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DOUGLAS-FIR TUSSOCK MOTH: AN ANNOTATED BIBLIOGRAPHY

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

Acknowledgments

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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USDA FOREST SERVICE
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DOUGLAS-FIR TUSSOCK MOTH–

An Annotated Bibliography

Robert W. Campbell

and

Lorna C. Youngs

Forestry Sciences Laboratory
Corvallis, Oregon

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PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture
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Foreword

This annotated bibliography includes references to 338 papers. Each deals in some way with either the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), or a related species. Specifically, 210 publications and 82 unpublished documents make some reference, at least, to the Douglas-fir tussock moth; 55 are concerned with other species in the same genus. The subject matter in each paper has been indexed to at least one general topic (General, Taxonomy, Biology, Host Relationships, Outbreaks, Control, Related Material). Most of these general topics have been subdivided into more specific headings. For example, Host Relationships includes separate categories for white fir, grand fir, and Douglas-fir. A complete listing of the references in each general and specific category is presented in the index.

By intent, at least, this bibliography is complete for the Douglas-fir tussock moth through December 31, 1977. A copy of virtually every document in the bibliography is on file at the Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon. Investigators wishing to obtain copies of specific documents are urged to write the author(s) directly. Usually, specific authors' current addresses can be obtained by writing the senior author of this bibliography. Copies of documents in our master file in Corvallis will only be supplied as a last resort.

Bibliography

1. Almas, D., W. Bousfield, L. Livingston, and W. Ludeman. 1975. 1974 North Idaho cooperative Douglas-fir tussock moth control project. Report. State Idaho, Dep. Lands. Div. For. Manage., Coeur d'Alene, Idaho. Rep. 75-1. 60 p.

"This report summarizes the results of a 1974 forest protection project using DDT for control of the Douglas-fir tussock moth." Signs that an outbreak was building up in northern Idaho were discovered at isolated spots in 1971 and 1972. An egg mass survey, conducted February 1973, substantiated the buildup. Another survey that fall showed 103,878 acres of forest with population that could cause damage in 1974.

Treatment boundaries for the project were based on 20 larvae per 1,000 in^2 of foliage. A total of 75,254 acres were sprayed with DDT at a rate of 3/4 lb of DDT per acre. Corrected larval mortality averaged 97.77% 4 days after spraying and 99.8% 21 days after spraying. Comparison of sprayed and unsprayed areas showed that a significant amount of foliage was saved by the spray.

Spray deposit was monitored in sprayed and buffered areas. Pesticide residues were monitored before, during, and after spray application in water, fish, and air.

Meat from livestock in the spray areas was inspected. Actual levels found in livestock were not presented.
Control - 2, 3

2. Anderson, W. B. 1919. Notes on the tussock moth, Hemerocampa vetusta gulosa Hy. Edw., in British Columbia. Agric. Gaz. Can. 6(2):139.

Two local infestations of the tussock moth, Hemerocampa vetusta gulosa Hy. Edw., were observed at Hedley and Chase, British Columbia, in 1917 and 1918. Douglas-firs were severely defoliated and

some top-kill was reported. Ponderosa pines were lightly attacked and many cocoons were found on them. The attacks started at the top of the crown and worked downward.

Related Material - 3

3. Atkins, E. L., Jr. 1958. The western tussock moth, Hemerocampa vetusta (Bdv.), on citrus in southern California. J. Econ. Entomol. 51(6):762-765.

"Larvae of the western tussock moth, Hemerocampa vetusta (Bdv.), caused economic losses in 10,000 acres of oranges during the springs of 1956 and 1957 in parts of southern California. Population levels were as high as 1,000 larvae per tree. The larvae may destroy the new spring flush of growth and the newly set fruit and scar maturing oranges so that the fruit drops or the grade is lowered. This moth has one generation a year. The wingless females lay their eggs on the trees in masses from May to July; the eggs hatch during March and April of the following year. The average life cycle is 75 days. A population level of 100 caterpillars per orange tree, or an average of one egg mass per tree, is considered the economic level. Six parasite species, one hyperparasite, and two predator species were collected during 1956 and 1957 and were observed to reduce the population approximately 50% in some groves. Chemical control studies showed that parathion, TDE (DDD), DDT, Dilan®, Guthion®, Sevin® (N-methyl-1-naphthyl - carbamate), methyl parathion, and Phosdrin® gave excellent control; nine other pesticides did not provide adequate control. Parathion, TDE, and DDT are now registered for use on citrus and are recommended for control of the western tussock moth when applied as complete foliage sprays at the rate of 2, 5, and 5 lbs, respectively, of actual toxicant per acre."

Related Material - 3

4. Austara, O., and T. Jones. 1971. Host list and distribution of lepidopterous defoliators of exotic softwoods in East Africa. East Afr. Agric. For. J. 36(4):401-413.

Lepidoptera that defoliate pines and cypresses in East Africa are listed, including _Orgyia basalis_, _O. hopkinsi_, and _O. mixta_.
Related Material - 3

5. Austara, O., and J. Migunda. 1971. _Orgyia mixta_ Snell. (Lepidoptera: Lymantriidae) a defoliator of exotic softwoods in Kenya. East Afr. Agric. For. J. 36(3):298-307.

"_Orgyia mixta_ Snell. is a native tussock moth which has adapted itself to feeding on exotic softwoods, and has occurred in small outbreaks in Kenya plantations. The biology of the pest was studied in the field and the laboratory. The duration of the life cycle ranged between 48 and 85 days, and it was concluded that the moth was potentially capable of producing up to six generations a year. It was estimated that approximately 20-25 larvae per meter of branch could cause 100% defoliation, and that young plantations are likely to be more vulnerable to attacks than older stands." A nematode parasite is the main agent of natural control. Three insecticides were tested against late-instar larvae.
Related Material - 3

6. Balch, R. E. 1930. The fir tussock moth (observations in 1929). USDA Bur. Entomol., For. Insect Invest., For. Insect Field Stn., Coeur d'Alene, Idaho. 19 p. Unpubl.

The results of preliminary investigations of three Douglas-fir tussock moth infestation sites in Idaho conducted during August 1929 are presented. A complete description of the insect in all stages of development and its life history are given. Larval feeding patterns are deduced from laboratory observations and examinations of tree defoliation. Host preference and species upon which the moth can reach epidemic proportions are listed. The possible effects of Douglas-fir tussock moth defoliation on stand composition and its commercial importance are discussed.

The cycle of epidemics and the possibility of natural control are discussed in detail. The role of an unidentified disease in natural control is mentioned. Several larval parasites and egg parasites are described in an appended section. Larval parasites include an unidentified fly; three ichnuemonid wasps, *Ephialtes sanguineipes* (Cress.), *Conoblasta fumiferanae* Vier., and *Theronia atalantae* var. *fulvescens* (Cress.); and an unidentified Pteromalidae. The fly is the most important larval parasite. Egg parasites are *Trichogramma minuta* Riley and *Telenomus* sp.
General Background; Biology - 1, 3

7. Balch, R. E. 1930. The fir tussock moth reveals ability to cause serious damage. For. Work. 6(2):17-18.

The Douglas-fir tussock moth caused extensive defoliation of fir in States from Nevada to British Columbia during 1929. It was described as a new species by McDunnough in 1921. In 1927, it was reported defoliating alpine fir in Jarbidge, Nevada. The next year it defoliated white fir and Douglas-fir in Idaho, Washington, and British Columbia. The epidemics appear to last 3 years. Parasitism and starvation caused heavy mortality. Burning, use of arsenicals, and the introduction of a predaceous beetle, *Calosoma sycophanta*, are suggested as control measures.
General Background, Biology - 3, Outbreaks - 2

8. Balch, R. E. 1932. The fir tussock moth (*Hemerocampa pseudotsugata* McD.). J. Econ. Entomol. 25(8):1143-1148.

"Practically simultaneous outbreaks of the fir tussock moth (*Hemerocampa pseudotsugata* McD.) have occurred in widely separated areas in the West during recent years. Considerable damage has been done in fir forests." A description is given of the stages, the habits and life history, and primary hosts by area for the moth. At Weiser, both Douglas-fir and grand fir in mixed stands were attacked, but grand fir was more heavily defoliated. At Northport, Washington, the reverse was

true. Cocoons and eggs were heavily parasitized; the parasites were reared and identified.
General Background; Biology - 1; Outbreaks - 2

9. Banowetz, G. M., J. L. Fryer, P. J. Iwai, and M. E. Martignoni. 1976. Effects of the Douglas-fir tussock moth nucleopolyhedrosis virus (Baculovirus) on three species of salmonid fish. USDA For. Serv. Res. Pap. PNW-214, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), and steelhead trout (Salmo gairdneri) showed no pathology when exposed to Baculovirus by three different routes. Cell lines derived from chinook salmon and steelhead trout were refractory to nonoccluded virions, and no cytopathology was observed by light and electron microscopy. Both polyhedra and nonoccluded virions were inactivated rapidly by coho salmon exposed to the virus by three different routes."
Control - 6

10. Barnes, H. F. 1900. New species and varieties of North American Lepidoptera. Can. Entomol. 32(2):42-48.

Orgyia oslari, n. sp., is described from one male specimen from Poncha Springs, Colorado.
Related Material - 3

11. Barnes, H. F. 1942. Unusual abundance of Notolophus (=Orgyia) antiqua L. (Lep., Lymantriidae). Entomol. Mon. Mag. 78(10):240.

In August 1942 near Penmaenmaur, N. Wales, a patch of bilberry was observed being defoliated by Notolophus (=Orgyia) antiqua. No parasites or predators were observed attacking the larvae.
Related Material - 3

12. Baugh, T. M. 1976. Pest management tests seek new control methods. West. Conserv. J. 33(4):34-36.

The highlights of the research of the Expanded Douglas-fir Tussock Moth Research and Development Program are presented. Effort is being directed toward the development of an integrated pest management program by 1977. Initial results of the program include: identification of the female sex pheromone and its use in sticky traps; promising tests of Dimilin®, carbaryl, and Dylox® as alternatives to DDT; effective control produced by microbial agents; and a greater understanding of the relationship between stand characteristics and outbreaks. Plans for future reasearch are briefly outlined.
Related Material - 2

13. Beckwith, R. C. 1975. Douglas-fir tussock moth Orgyia pseudotsugata (McD.) (Lepidoptera: Lasiocampidae): influence of host foliage. J. N.Y. Entomol. Soc. 83(4):282-283.

"A resume of tussock moth biology is presented with special emphasis on host effects. . . . Populations can increase equally well on grand fir and Douglas-fir, the degree of acceptance of old-growth foliage may govern survival rate and ultimate tree damage." Only current foliage is consumed during the release phase of an outbreak, but larvae will feed on old-growth foliage during the outbreak phase. Subsistence on old-growth foliage by early instar larvae is ultimately detrimental to survival.
Biology - 1; Host Relationships - 2, 3

14. Beckwith, R. C. 1976. Influence of host foliage on the Douglas-fir tussock moth. Environ. Entomol. 5(1):73-77.

"Douglas-fir tussock moth (Orgyia pseudotsugata (McDunnough)) larvae were fed foliage obtained from the top and bottom of the crowns of Douglas-fir, grand fir, and subalpine fir under controlled laboratory

conditions. High-density field populations were simulated by forcing larvae to feed upon old-growth foliage creating a stress factor that was detrimental to the population. The host plant and crown position had a significant effect on frass production, head-capsule size, and pupal weight. The number of eggs produced was significantly greater from foliage obtained from the top of the crown. The most significant factor was whether larvae were forced to feed on old-growth foliage. This "stress" resulted in increased development time, frass production, number of instars and decreased head-capsule size, and egg production."
Biology - 1; Host Relationships - 2, 3

15. Bedard, W. D. 1938. An annotated list of the insect fauna of Douglas-fir (Pseudotsuga mucronata Rafinesque) in the northern Rocky Mountain region. Can. Entomol. 70(9):188-197.

A record is given of insects that have been found in or on Douglas-fir in the northern Rocky Mountain region by personnel of the Forest Insect Field Laboratory at Coeur d'Alene, Idaho. It includes insects that feed on the tree as well as the parasites and associates of those insects. Most of the 153 species listed were collected by the writer during a study of the Douglas-fir beetle. Hemerocampa pseudotsugata is listed, and sporadic outbreaks have been recorded in various parts of the northern Rocky Mountains. Adults are prevalent in the infested areas during September.
Host Relationships - 3

16. Bergstrom, D. 1976. Pheromones for insect control. In Forestry research: What's new in the West, September 1976. USDA For. Serv., p. 9-10.

The possible uses of the synthetic sex pheromone of the Douglas-fir tussock moth as a control agent, as well as a survey and detection tool, are explored. The procedure used to isolate and identify insect pheromones is briefly outlined.
Biology - 2, Outbreaks - 2, 3; Control - 10

17. Berryman, A. A. 1973. Population dynamics of the fir engraver, Scolytus ventralis (Coleoptera: Scolytidae). 1. Analysis of population behavior and survival from 1964 to 1971. Can. Entomol. 105(11):1465-1488.

"Populations of the fir engraver reached epidemic proportions and then declined to a very low level over the study period (1964-71). . . . The population trend over the past 40 years was associated to some degree with rainfall deficits and with Douglas-fir tussock moth outbreaks."
Host Relationships - 2, Outbreaks - 5.

18. Bischoff, A. I., and J. D. Linn. 1967. Completion report on the evaluation of the effects on fish and wildlife of the Douglas-fir tussock moth control project in California - 1965. Calif. Dep. Fish and Game. 4 p. Unpubl.

"In 1965, the California Department of Fish and Game initiated a 2-year surveillance program to determine the effects of a DDT forest spray program on nontarget fish and wildlife." This paper is an addendum to a 1965 progress report on the first year's results. Residue in the environment increased considerably, with a general buildup of DDT residues in wild animals following the DDT application. "The highest levels of the DDT complex were reported in samples of chickadees (51.5 ppm) and deer (84.1 ppm). The residue levels reported for the 1-year postspray samples of these species declined nearly to the prespray levels."
Control - 3

19. Blackmore, E. H. 1919. Report of the Provincial Museum of Natural History, for 1918. Victoria, B.C. 16 p.

A summary is given of work carried out by the museum during the year. Damage done by various species of insects is recorded, as well as

their relative abundance. A list of rare and uncommon insects taken in British Columbia is presented, along with the new specimens described in the province. One of the newly described species of Lymantriidae is Hemerocampa vetusta gulosa Hy. Edw. A brief sketch of its biology is given. Photographs of the new species are included.
Related Material - 3

20. Bogenschütz, V. H. 1975. Parasitenstudien als Entscheidungshilfen bei der integrierten Bekampfung von Forstschadlingen. [Parasite studies as aids in decision-making in the integrated control of forest pests.] Z. Angew. Entomol. 78(1):1-4. [In Ger.]

This paper deals with studies on parasites for integrated control in forests. "The results of the studies on parasitism of the two spruce damaging insects Orgyia antiqua and Laspeyresia pactolana provided not only better knowledge of the ecology of these lepidopterous species but also indicate the importance of host-parasite-relationships as they apply to forest and environmental protection."
Related Material - 3

21. Bousfield, W. E. 1974. Sampling the target insect. In Aerial application of insecticides against forest defoliators (chemicals and microbials). Proceedings of workshop held April 23-25, 1974, Univ. Mont., Missoula, p. 107-111. USDA For. Serv., State and Private Forestry, Northern Region, Missoula, Mont.

Techniques are described for sampling the target insect to measure the efficacy of aerial operations. Formulas for estimating the population variance between branches, trees, and areas or clusters of trees for estimating sample size and unit are included.
Outbreaks - 3

22. Boving, P. A., B. Maksymiuk, R. G. Winterfeld, and R. D. Orchard. 1971. Equipment needs for aerial application of microbial insecticides. Trans. Am. Soc. Agric. Eng. 14(1):48-51.

General principles of aerial application of microbial insecticides are outlined. Objectives of this study were to examine the physical performance of selected or developed equipment suitable for aerial application of virus in water-based spray formulations. "Ultra-low and low-volume spray systems mounted on a helicopter were developed for aerial application of microbial sprays in water-base, and possibly other, spray formulations. These spray systems eliminated heating of the spray liquid and minimized possible injury to the pathogens." A spray droplet size of 100-um mass median diameter is needed, because it will not clog passages or openings in fine spray nozzles.
Control - 9

23. Breillatt, J. P., J. N. Brantley, H. M. Mazzone, M. E. Martignoni, J. E. Franklin, and N. G. Anderson. 1972. Mass purification of nucleopolyhedrosis virus inclusion bodies in the k-series centrifuge. Appl. Microbiol. 23(5):923-930.

"Nucleopolyhedrosis virus inclusion bodies specific for *Hemerocampa pseudotsugata*, *Neodiprion sertifer*, *Porthetria dispar*, and *Heliothis zea* have been purified by using a continuous-sample-flow-with-isopycnic-banding centrifuge in quantities up to 6 x 10 polyhedral inclusion bodies per day. Countinuous flow methods for S-$_{p}$ type purification have been evolved to deal with mass isolation of bioparticles. . . . The inclusion bodies purified by this method are free from insect components and debris on microscopy examination."
Control - 6

24. Breillatt, J. P., M. E. Martignoni, and N. G. Anderson. 1969. Virus isolation for large scale insect destruction. Biophys. J. Soc. Abstr.:A-262. (SAM-J10.)

Nucleopolyhedrosis virus inclusion bodies are effective specific biological insecticides with the potential for replacing chemicals. "Their widespread use requires a large scale purification method for removal of bacterial contaminants." Inclusion bodies from Hemerocampa pseudotsugata and Heliothus zea could be purified in a new continuous-flow rotor constructed for the K-series zonal centrifuge. "This rotor (K-X) permits isolation of particles from a stream flowing over 6.7 liters of gradient at rotor velocities of up to 35,000 rpm. The particles can then be banded at their isopycnic point in the gradient. Inclusion bodies from H. zea have been successfully purified in this rotor."
Control - 6

25. Buckhorn, W. J. 1947. Second memorandum of the Douglas-fir tussock moth outbreak near Troy, Oregon. USDA For. Insect Lab., Portland, Oreg. 8 p. Unpubl.

"This memorandum is a detailed supplement to the memorandum of September 23, 1946, in which the Douglas-fir tussock moth outbreak near Troy, Oregon, was briefly reported." The outbreak was found August 20, 1946, on 10,000 to 12,000 acres, of which 500 to 600 acres were completely defoliated. Based on large numbers of egg masses found, the author predicted that the population was increasing and would cause considerable tree mortality in 1947. The results of an aerial survey in 1947 showed 56,065 acres being defoliated. The primary hosts, Douglas-fir and white fir, comprise less than half of the volume threatened. Logistics of possible control and salvage operations are discussed.
Outbreaks - 2

26. Buckhorn, W. J. 1948. Douglas-fir tussock moth history and extent of outbreaks. USDA For. Insect Lab., Portland, Oreg. 4 p. Unpubl.

All major outbreaks of the Douglas-fir tussock moth occurring in the United States and Canada are reported. Extent of the outbreaks and

control measures used are cited. Also mentioned was the initiation in 1947 of a study to determine the viability and parasitisms of egg clusters from the Troy, Oregon, area.
Outbreaks - 1, 2

27. Buckman, R. E. 1974. Deadly tussock moth threatens more timber stands in Pacific Northwest. West. Conserv. J. 21(1):25-31.

A popular account is given of the tussock moth outbreak in the Blue Mountains and the methods of control. A brief review of the biology of the moth, detection and prediction of population trends, impact of defoliation, and alternatives for control is presented. The use of DDT is called for if the natural virus incidence is too low to suppress the outbreak population.
Outbreaks - 2

28. Burke, H. E. 1906. Notes on the natural history of *Notolophus oslari*. *In* Minutes of the 209th regular meeting of the Entomological Society of Washington. Proc. Entomol. Soc. Wash. 8(1,2):142-143.

During the 209th meeting of the Entomological Society of Washington, the author exhibited a rare tussock moth, *Notolophus oslari* Barnes. This was the first record of this species from California. A discussion followed on the damage done by the larvae to fir, comparisons between the egg mass construction of *N. oslari* and other closely related species, and possible biological control agents.
Related Material - 3

29. Burke, H. E. 1930. Which insects are the important enemies of shade, park, and ornamental trees in the Pacific States? J. Econ. Entomol. 23(5):783-785.

Fifty of the most important insect enemies of trees used for ornamental, shade, and recreational purposes in the Pacific States are ranked in importance according to the information provided by questionnaires sent to university, city, county, State, and Federal personnel working with insects. The importance of any species varies with the area. Hemerocampa pseudotsugata McD. was rated number 39.
General Background

30. Cameron, E. A. 1970. Larval eclosion in Douglas-fir tussock moth, Hemerocampa pseudotsugata. Ann. Entomol. Soc. Am. 63(4):1110-1113.

Douglas-fir tussock moth "eggs were field collected in northeastern California, early in December 1965, treated with a solution of formaldehyde for virus decontamination, then stored at 2-3°C. After storage for 18-360 days, eggs were observed for percent of eclosion and duration and diel periodicity of eclosion."

"Both percent eclosion and the duration of the eclosion period were reduced by storage up to 186 days. No eggs hatched after 360 days storage. Low hatchability after long periods of storage may have resulted from formaldehyde fumigant action, suffocation, or depletion of stored energy by maintenance metabolism.

"Continuous illumination or constant darkness following storage influenced neither the initiation of eclosion nor the duration of the eclosion period. Eclosion was highest in the 6-hr period which included sunrise, but continued throughout the diel. Implications of such a pattern on larval establishment and dispersal in nature are discussed."
Biology - 1

31. Campbell, R. W. 1977. Integration of program outputs: Development of a pest management system. Bull. Entomol. Soc. Am. 23(3):179-180.

Three models are being constructed: the stand outbreak model, the stand prognosis model, and a socioeconomic model to be incorporated into the Douglas-fir tussock moth pest management system. An overview of the management system and the interactions of the models within the system are presented.
Control - 11, Related Material - 2

32. Campbell, R. W., and M. W. McFadden. 1977. Design of a pest management research and development program. Bull. Entomol. Soc. Am. 23(3):216-220.

The design of a pest management research and development program is described in terms of a specific program now in existence, the Douglas-fir Tussock Moth Research and Development Program. The article emphasizes the function rather than the structure of the program. Planning, implementation, evaluation, and updating are discussed as they relate to the overall accountability of the project. The goal of establishing clear and reachable program objectives and of integrating individual studies into a cohesive pest management plan is stressed. The article concludes with a discussion of the problems encountered in the development of the tussock moth program and the criteria for establishing an idealized pest research and development program.
Related Material - 2

33. Campbell, R. W., K. H. Wright, M. W. McFadden, and J. E. Dewey. 1978. USDA Douglas-fir tussock moth reasearch and development program. J. For. 76(1):37-40.

"In 1974 the U.S. Department of Agriculture initiated the four-year Expanded Douglas-fir Tussock Moth Research and Development Program to provide: (1) a short-range opportunity to summarize and put into use existing methods to reduce damage, and (2) a longer range opportunity to develop knowledge necessary to prevent or suppress future outbreaks.

Program objectives have been met on schedule through the first three years, and the task of the fourth year is to document and disseminate the findings."
Related Material - 2

34. Canada Department of Forestry. 1962. Forest Lepidoptera of Canada. Bull. 128(vol. 2):259-264.

Species of Liparidae, Orgyia antiqua, O. pseudotsugata, O. plagiata, and O. leucostigma are characterized by distribution, host range, feeding type, prevalence, and seasonal occurrence.
Biology - 1; Related Material - 3

35. Canutt, P. R. 1974. Monitoring pesticide residues in nontarget organisms. In Aerial application of insecticides against forest defoliators (chemicals and microbials). Proceedings of workshop held April 23-25, 1974, Univ. Mont. Missoula, p. 112-116. USDA For. Serv., State and Private Forestry, Northern Region, Missoula, Mont.

Monitoring nontarget organisms is discussed in relation to the proposed Blue Mountain Douglas-fir tussock moth control project using DDT. Monitoring is defined as the measurement of "changes with time of the concentration of introduced chemicals in all parts of the forest environment." The proposed plans for monitoring DDT effects on insectivorous birds, aquatic organisms, and DDT residues in livestock and vegetation are briefly outlined. Included is a general discussion on the needs for environmental monitoring and how it should be coordinated with the control program.
Control - 3

36. Capizzi, J. 1974. Douglas-fir tussock moth control by the homeowner. For. Serv. Coop. Ext. Serv., FS 214, 2 p. Oreg. State Univ., Corvallis.

The life history of tussock moth and damage caused by it are presented, along with pictures of the different life stages. Control of the insect on ornamental trees is obtained by the use of methoxychlor or Bacillus thuringiensis (Dipel®) spray application.
General Background

37. Carnegie, J. W., and G. S. Beaudreau. 1969. Deoxyribonucleic acid synthesis in insect larvae after inoculation with nucleopolyhedrosis virus. J. Virol. 4(3):311-312.

DNA synthesis by Hemerocampa pseudotsugata after inoculation with nucleopolyhedrosis virus occurs in a large burst, 72 to 96 hr after infection and continues through the 5th day of the disease cycle.
Biology - 5

38. Chauthani, A. R., and D. Claussen. 1968. Rearing Douglas-fir tussock moth larvae on synthetic media for the production of nuclear polyhedrosis virus. J. Econ. Entomol. 61(1):101-103.

"A technique for rearing larvae of the Douglas-fir tussock moth, Hemerocampa pseudotsugata McDunnough, in large numbers on a synthetic medium for the production of nuclear polyhedrosis virus is described. The insect was reared from the egg stage generally to the 4th and 5th instar before infection." Egg masses were collected from the field and stored at 4°C to fulfill diapause requirements. Surface sterilization of the egg with a 10% formaldehyde solution provided virus-free larvae. The synthetic diet used to rear the larvae is included. Virus infection of the larvae was initiated 25 days after eclosion, when larvae had an average weight of 310 mg. Infected larvae were collected 8-12 days after infection, lyophilized, and placed in vacuum sealed jars. Mortality of larvae before infection was very low.
Biology - 6; Control - 9

39. Ciesla, W. M. 1975. Pilot control projects of chemical and microbial insecticides against Douglas-fir tussock moth - 1974. West. For. and Conserv. Assoc., Perm. Assoc. Proc. 1974:16-18. Portland, Oreg.

Tests of chemical and microbial insecticides were carried out in 1974 to find an alternative to DDT for controlling the Douglas-fir tussock moth. Five pilot control projects were conducted: Sevin-4-oil and *Bacillus thuringiensis* (*B.t.*), applied near Missoula, Montana, with Sevin-4-oil causing a 90 to 99% reduction in population and *B.t.* causing a 73% reduction; Sevin, Dylox, and DDT, applied near Halfway, Oregon, with Sevin causing a 53-89.5% reduction, Dylox with a 70-83.1% reduction, and DDT a 100% population reduction; *B.t.* and nucleopolyhedrosis virus applied in Idaho, with both sprays aborted because of a 93% population reduction from natural virus infection; Sevin-4-oil applied in Idaho, with an 83.15-96.77% population reduction; and Dylox in Oregon, with a 68.4% and 78.6% reduction before a natural population collapse occurred. Problems encountered during the spray programs were discussed.
Control - 1, 2, 5, 6

40. Ciesla, W. M. 1977. Douglas-fir tussock moth: Direct control with chemical and microbial insecticides. Bull. Entomol. Soc. Am. 23(3):174-176.

The effort directed toward the development of chemical and microbial insecticides for Douglas-fir tussock moth control is described. Laboratory screening procedures, field experiments, and pilot control projects have been directed toward bringing carbaryl, trichlorfon, acephate, and TH 6040 to or close to registration. *Bacillus thuringiensis* and the tussock moth nucleopolyhedrosis virus have been tested. Improvement of application technology has also received considerable research attention.

The research has resulted in the registration of Thuricide 16B (commercial B.t. formulation) and the nucleopolyhedrosis virus for tussock moth control.
Control - 1, 5, 6, 7

41. Ciesla, W. M., S. Kohler, J. E. Dewey, and M. D. McGregor. 1976. Field efficacy of aerial applications of carbaryl against Douglas-fir tussock moth. J. Econ. Entomol. 69(2):219-224.

"Sevin-4-oil, an oil suspension of carbaryl, was applied by helicopter to forested areas infected by Orgyia pseudotsugata (McDunnough), in western Montana and northern Idaho. Dosage was 2 lb AI/0.75 gal of carrier/acre. Spray was applied to 1st-instar larvae in Montana and 3rd and 4th instars in Idaho. Treatments provided a high degree of insect mortality and measurable foliage protection; the residual population did not produce egg masses in suffient quantity to repopulate infested areas."
Control - 1

42. Cleary, B., and J. Brown. 1974. After the tussock moth: salvage, rehabilitation, protection: A guide for forest landowners. Oreg. State Univ. Ext. Serv. Spec. Rep. 422, 35 p.

This publication discusses tussock moth damage, salvage cutting opportunities, rehabilitation and reforestation methods, protection measures, available help, and applicable State laws. Appended are lists of local sawmills, tree nurseries, helpful publications, and important tree species in the northeastern Oregon and eastern Washington forests.
General Background; Outbreaks - 5

43. Cole, W. E. 1957. Douglas-fir tussock moth appraisal survey in Owyhee County, Idaho. USDA For. Serv. Intermt. For. and Range Exp. Stn., Ogden, Utah. 4 p. Unpubl.

An infestation of the Douglas-fir tussock moth was detected in August 1956. An appraisal survey was conducted in September 1957, and about 26,000 acres were found infested. The author predicted that defoliation would occur again in 1958 even though he found a high degree of parasitism.
Outbreaks - 2

44. Cole, W. E. 1958. Douglas-fir tussock moth situation in Owyhee County, Idaho, 1958. USDA For. Serv. Intermt. For. and Range Exp. Stn., Ogden, Utah. 4 p. Unpubl.

In August 1956, an infestation of the Douglas-fir tussock moth was reported in the Owyhee Mountains, Idaho. Defoliation ranged from 60 to 70%, and a high degree of parasitism was evident. The area was checked in 1957 and defoliation estimated at less than 50% with 19.5% pupal parasitism. Large numbers of sawfly larvae were present also. Control operations by aerial spraying were recommended, and plans were formulated. But in late 1957 dead larvae and pupae were found showing symptoms of virus disease. Presence of virus was confirmed, and control plans were cancelled. The area was sampled each month from June through October 1958 for feeding of tussock moths and sawflies, but only for the tussock moth pupal population. Populations of both tussock moths and sawflies had greatly decreased in all but one area. Larval samples were taken and analyzed for the amount of virus present.
Outbreaks - 2

45. Condrashoff, S. F., and J. Grant. 1962. Sampling Douglas-fir tussock moth populations. Can. Dep. For., For. Entomol. and Pathol. Branch Bi-Mon. Prog. Rep. 18(4):3.

In the summer of 1961 several localized infestations of the Douglas-fir tussock moth were observed in the North Okanagan, British

Columbia. "Three sample plots were established in separate areas to detect any future expansion of the infestations, to assess tree mortality and to obtain information on distribution of cocoons and egg masses in the trees. . . . Severely defoliated trees contained over twice the concentration of cocoons of the lightly defoliated trees, whereas the average concentration of egg masses was about equal." Male and female larvae pupate in different sites--females in green foliage and males more or less at random. Successful emergence of adults decreased with crown level.
Outbreaks - 3

46. Congressional Record - House. 1969. A technological alternative to pesticides. June 27, 1969:17646. H5359.

On June 27, 1969, Mr. Hosmer of California, spoke about a virus which is specific for the Douglas-fir tussock moth as an alternative to DDT control. The USDA Forest Service is working with the Atomic Energy Commission's Oak Ridge National Laboratory to purify the virus. Dr. M. E. Martignoni established the toxicity of the virus toward the tussock moth and asked that the project be initiated. The zonal centrifuging system with a K-11-C rotor system was used to purify the virus. The centrifuge system reduces the bacteria present in the virus homogenate to a level safe for use on watersheds.
Control - 6

47. Crisp, W. 1974. The tussock moth scare, will it collapse? Am. For. 80(4):58-63.

This paper is a report on the EPA public hearing of January 1974 on the USDA Forest Service application to use DDT against the current Douglas-fir tussock moth infestation in Washington, Oregon, and Idaho. Proponents of the use of DDT were led by Senator Robert Packwood, and the opposition was represented by William Van Dyke of OSPIRG. Arguments for

DDT were based on the potential damage to timber and watershed values if the outbreaks were not quickly halted, coupled with the lack of registered alternative chemical controls. OSPIRG and the Oregon Environmental Council questioned the Forest Service estimate of potential damage and its test results with other chemical agents. They contended that the benefits of DDT use did not outweigh the hazards.
Control - 4

48. Crouch, G. L., and R. F. Perkins. 1968. Planning a surveillance program for the Douglas-fir tussock moth in Oregon. Pestic. Monit. J. 2(2):97-100.

"This is a brief account of the planning and organizing of a surveillance team to determine the adverse effects, if any, of a forest aerial spray project. Particular effort was made to ensure that all interested persons, organizations, and agencies were advised of the proposed project well in advance and invited to participate on the surveillance team. . . . Final plans called for gathering short-term information on the effects of proposed DDT application on big game, range cattle, forage plants, water, aquatic insects, and fish. Long-term research will investigate levels and persistence of DDT in aquatic environments and movement of DDT and its metabolites from conifer litter through soil particles."
Control - 3

49. Crouch, G. L., and R. F. Perkins. 1968. Surveillance report, 1965 Burns Project, Douglas-fir tussock moth control. Malheur and Ochoco National Forests. USDA For. Serv. Pac. Northwest Reg., Insect and Dis. Control Branch, Div. Timber Manage. 20 p. Unpubl.

This report provides a record of the buildup of an infestation of the Douglas-fir tussock moth near Burns, Oregon, in 1965 and the control and surveillance efforts used to suppress it. In 1963, 15 acres were

defoliated by the moth, and by 1964, 41,000 acres had become infested. Entomologists predicted that 200,000 acres would become infested in 1965 unless control measures were applied. They predicted that virus incidence was too low to cause a population collapse, and DDT was selected for control. An analysis for DDT residues was conducted on aquatic organisms, big game animals, range cattle, and forage plants. Few visible adverse effects of the spray project on nontarget organisms were observed. Control - 2, 3

50. Cunningham, J. C. 1972. Preliminary studies of nuclear polyhedrosis viruses infecting white marked tussock moth, Orgyia leucostigma. Can. For. Serv. Insect Pathol. Res. Inst. Inf. Rep. 11 p. Unpubl.

"Larvae of Orgyia leucostigma were found to be susceptible to nuclear polyhedrosis viruses isolated from Hemerocampa (Orgyia) pseudotsugata and O. antiqua as well as to their homologous virus. A very marked difference in susceptibility to virus was found between first- and fourth-instar larvae, the fourth-instar larvae being extremely resistant. It is recommended that field applications of the virus be made when the larvae are in the first instar, and an approximate dosage rate is suggested." Related Material - 3

51. Dahlsten, D. L., E. A. Cameron, and W. A. Copper. 1970. Distribution and parasitization of cocoons of the Douglas-fir tussock moth, Hemerocampa pseudotsugata (Lepidoptera: Lymantriidae), in an isolated infestation. Can. Entomol. 102(2):175-181.

"Douglas-fir tussock moth cocoons were collected and their distribution recorded by crown level on white fir, Abies concolor, in northeastern California. Nine trees were sampled in two defoliation classes, light (20 to 30% defoliated) and moderate to heavy (50 to 80% defoliated). Cocoons were more abundant in the lower crown levels as defoliation became greater. The proportion of female cocoons increased toward the lower levels of the crown. An overall sex ratio of 1.2 males:1.0 females was recorded. Significantly more male cocoons were

parasitized than female. A list of the natural enemies of the tussock moth in the study area is given." Parasitization played an important part in the collapse of the population. In addition, some females emerged successfully from their cocoons but did not oviposit. This may have been due to the virus disease present in the epidemic population in 1965. Biology - 3; Host Relationships - 1; Outbreaks - 4

52. Dahlsten, D. L., and R. F. Luck. 1972. Evaluation of the natural enemy complex of the Douglas-fir tussock moth at three sites in the El Dorado National Forest. Part VI. In Results of field experiments for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus and associated studies. Progress report. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. 4 p. Unpubl.

This preliminary report is on a study to determine the natural enemy complex of the tussock moth, to associate the various parasites and predators with the stages of the life cycle of the moth, and to evaluate their impact on these stages. Alternate hosts of the natural enemies were sampled as well. The study included an attempt to describe the complex of spiders on white fir and to evaluate their effectiveness as predators of the tussock moth. Eggs, larvae, and cocoons were sampled and laboratory reared to determine parasites. A partial list of known natural enemies of the tussock moth in El Dorado County is presented as is a preliminary listing of the percent of egg and cocoon parasitization. Biology - 3; Host Relationships - 1

53. Dahlsten, D. L., R. F. Luck, E. I. Schlinger, J. M. Wenz, and W. A. Copper. 1977. Parasitoids and predators of the Douglas-fir tussock moth, Orgyia pseudotsugata (Lepidoptera: Lymantriidae), in low to moderate populations in central California. Can. Entomol. 109(5):727-746.

"Douglas-fir tussock moth, Orgyia pseudotsugata (McDunnough), populations were studied on white fir at four areas in central Sierra

Nevada mountains of California during 1971-73. Life tables were constructed for four populations in El Dorado County. The number of eggs per egg mass decreased and the percentage eggs parasitized doubled with declining moth populations. Hymenopterous parasitoids were collected from all immature stages of the moth: 1 egg parasitoid, Telenomus californicus Ashmead, 6 species of larval parasitoids, principally, Hyposoter sp., and 13 species of larval-pupal parasitoids. Tachinids were predominant and accounted for 73% of the parasitoidism of the cocoons in 1971. The apparent mortality of female pupae due to the parasitoid complex was greater than 97% in 1971 and 75% in 1972. One population in Placer County collapsed in 1971, apparently due to a combination of heat exhaustion and low levels of virus infection. Other defoliators, spiders, and several predatory insect species were collected from the foliage samples simultaneously with the tussock moth during larval sampling. Twelve species of 'free living' spiders which could be capable of preying on the defoliator complex of white fir were collected. Parasitoids and predators appear to be potentially important biotic factors at low to moderate host population levels. This is the first recorded case where an agent other than the nucleopolyhedrosis virus has been responsible for the collapse of a Douglas-fir tussock moth population."
Biology - 3, Host Relationships - 1.

54. Dahlsten, D. L., and G. M. Thomas. 1969. A nucleopolyhedrosis virus in populations of the Douglas-fir tussock moth, Hemerocampa pseudotsugata, in California. J. Invertebr. Pathol. 13(2):264-271.

"A nucleopolyhedrosis virus of the Douglas-fir tussock moth, Hemerocampa pseudotsugata, was found in the white fir forests of California for the first time. Tussock moth populations declined in 1965, and this virus may be one of the important mortality factors. Egg masses were collected in selected study areas and the larvae reared in petri dishes on an artificial diet. Larvae were also collected in several instars during the course of the summer and reared individually in petri dishes. An attempt was made to design a survey technique that would indicate the rate of decline, due to virus, of tussock moth populations in the field.

Further refinement will be necessary before egg-mass collections can be used as a survey tool, but these studies indicate a good potential. Evidence from this study shows the rate of dying in sample dishes in the laboratory to be related to the rate of larval mortality in the field. The primary use of such a survey would be an indicator to those making pest control decisions."
Biology - 5

55. Daterman, G. E., R. L. Livingston, and R. G. Robbins. 1977. How to identify tussock moths caught in pheromone traps. U.S. Dep. Agric., Agric. Handb. 517, 14 p. Combined Forest Pest Research and Development Program.

Sticky traps baited with synthetic tussock moth pheromone ((Z)-6-heneicosen-11-one) used to detect and monitor Douglas-fir tussock populations, frequently attract moths of closely related species. This pictorial guide identifies species likely to be trapped between August and mid-November in the Western U.S. and British Columbia. The guide distinguishes O. pseudotsugata, O. cana, O. antiqua, O. leucostigma, Dasychira vagans grisea, D. grisefacta ella, and species of Geometridae.
Biology - 2; Outbreaks - 2, 3.

56. Daterman, G. E., L. J. Peterson, R. G. Robbins, L. L. Sower, G. D. Daves, Jr., and R. G. Smith. 1976. Laboratory and field bioassay of the Douglas-fir tussock moth pheromone, (Z)-6-heneicosen-11-one. Environ. Entomol. 5(6):1187-1190.

"Laboratory bioassay demonstrated that the pheromone (Z)-6-heneicosen-11-one, its (E)-stereoisomer, and an epoxide (Z)-6,7-epoxyheneicosen-11-one are all attractive to the male Douglas-fir tussock moth, Orgyia pseudotsugata (McDunnough). The pheromone was approximately 27 times more attractive than the (E)-isomer and 300 times more attractive than the epoxide. An alcohol, (Z)-6-heneicosen-11-ol, was found to have a weak inhibitory effect on pheromone response.

"In the field, dosages of synthetic pheromone as low as 10 ng captured males and 50-ng baits were still attractive after 7 days' exposure. A controlled-release formulation, emitting pheromone at an estimated rate of 4 ng/min at 25°C, approached but did not equal the attractiveness of a live female. It is likely that an additional compound is present in the natural pheromone that is required to optimize response to the synthetic preparation.

"(Z)-heneicosen-11-one is also an effective attractant for the western tussock moth, _O. cana_ Edwards, the rusty tussock moth, _O. antiqua_ (Linn.), _Dasychira vagans grisea_ (Barnes and McDunnough), and _D. grisefacta ella_ Bryk."
Biology - 2; Related Material - 3

57. Daterman, G. E., and L. L. Sower. 1977. Douglas-fir tussock moth pheromone research using controlled-release systems. 1977 Int. Controlled Release Pestic. Symp. Proc., August 22-24, Corvallis, Oreg., p. 68-77. Oreg. Agric. Exp. Stn., and Coll. Sci., Oreg. State Univ., Corvallis.

The research effort with the sex pheromone of the Douglas-fir tussock moth to devise survey and control techniques and the requirements of a controlled release system for pheromone dissemination are examined. Survey trapping requires a weak but long-lasting pheromone bait system that can capture moths in proportion to population numbers. Strong baits fill traps to capacity in a short time even in low populations. Control of the tussock moth with pheromones requires a high rate of release to achieve mating disruption. The formulations necessary to satisfy these requirements are discussed.
Biology - 2, Outbreaks - 2, 3; Control - 10

58. Dewey, J. E. 1975. Douglas-fir tussock moth research and development highlights. West. For. and Conserv. Assoc., Perm. Assoc. Proc. 1975:66-67. Portland, Oreg.

Highlights of the accomplishments of the 3-year USDA Expanded Douglas-fir Tussock Moth Research and Development Program are presented. Information has been gathered on factors of natural population control, physical and geographic factors contributing to outbreak populations, uses of Douglas-fir tussock moth sex pheromones, possible chemical and microbial insecticides for tussock moth control, and improved methods of aerial application of insecticides.
Related Material - 2

59. Dodge, H. R. 1956. An analysis of Douglas-fir tussock moth cocoons, winter of 1955-56, with reference to the trend of the current outbreak in eastern Washington. USDA For. Serv. Intermt. For. and Range Exp. Stn., Missoula, Mont. 9 p. Unpubl.

In the summer of 1955 the Douglas-fir tussock moth defoliated 9,000 acres in eastern Washington. A ground survey of cocoons was made in the winter of 1955-1956 to determine whether aerial spraying would be necessary. Cocoons were collected from three areas--one in the main forest infestation, another where farmsteads adjacent to the forest were infested, and the last one where firs are found only on farmsteads. A low ratio of new to old egg masses was found, indicating a subsiding population in all areas. Only 14.3% of the total cocoons yielded egg masses. Parasitism in the forested region was 71.3%; in the farmstead regions it was 35.6 - 60.0%. Survival of the eggs appeared to be good, and larvae hatched abundantly in the laboratory. Since the age of the cocoons could not be determined, the parasitism counts were subject to some error. The infestation will probably subside in the forested region but will continue in the farmsteads because of low parasitism.
Outbreaks - 2

60. Dodge, H. R. 1956. Instructions for the control of the tussock moth in northeastern Washington in 1956. USDA For. Serv. Intermt. For. and Range Exp. Stn., Missoula, Mont. 6 p. Unpubl.

Instructions are given for Douglas-fir tussock moth control in small severe outbreaks, such as the farmstead infestations which charaterized the 1953-54 Colville, Washington, epidemic. In these infestations, small groups of fir trees, surrounded by farm land, had severe defoliation and a low rate of parasitism. Control measures include aerial or ground application of DDT or lead arsenate. Timing of application and application procedures are discussed.
Control - 1, 2.

61. Dodge, H. R. 1956. Tussock moth threatens timber. West. Conserv. J. 13(1):36, 40, 42-43, 45, 50.

A popular account is given of a tussock moth outbreak in Washington and Idaho. Life history, population dynamics, natural control factors, and damage are discussed.
Outbreaks - 2

62. Dodge, H. R. 1958. Insect survey program report (Douglas-fir tussock moth, Pinal Mountains, Arizona). USDA For. Ser. Intermt. For. and Range Exp. Stn., Missoula, Mont. 2 p. Unpubl.

Results of a survey of Douglas-fir tussock moth cocoons taken in May 1958, in the Pinal Mountain infestation show: an extremely high ratio of new egg masses compared with old egg masses or total cocoons; a sex ratio of three females per male; total mortality of cocoons at 36.8%; and an average of 200 eggs per mass. The Pinal Mountain infestation apparently contained a population capable of considerable damage in 1958.

Incubation of 35 of the sampled egg masses yielded 75 larvae per mass.
Outbreaks - 2

63. Dodge, H. R., and G. C. Trostle. 1964. Douglas-fir tussock moth. USDA For. Serv. For. Pest Leafl. 86, 7 p.

This leaflet briefly surveys the cycle of Douglas-fir tussock moth outbreaks, the host range, and the evidence of infestation. It includes a description of the larvae and adult moths, the life history and habits, the natural enemies, and the alternatives for chemical control.
General Background

64. Downing, K. B., P. B. Delucchi, and W. R. Williams. 1977. Impact of the Douglas-fir tussock moth on forest recreation in the Blue Mountains. USDA For. Serv. Res. Pap. PNW-224, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Outbreaks - 5

65. Dronka, K. 1974. Znamieniowka tarniowka -- niebezpieczny skodnik sadow jabloniowych. [Rusty tussock moth, a dangerous pest of apple orchards.] Owoce Warz Kwiaty 13(6):10-11. [In Polish.] Translation unavailable.
Related Material - 3

66. Dumbauld, R. K., H. E. Cramer, and J. W. Barry. 1975. Application of meteorological prediction models to forest spray problems. U.S. Army Tech. Note. Dugway Proving Ground, Dugway, Utah. (TECOM Project No. 5-CO-403-000-051.) In Aerial application of insecticides against forest defoliators (chemicals and microbials). Proceedings of workshop held April 23-25, 1974, Univ. Mont., Missoula, p. 32-71. USDA For. Serv., State and Private For., North. Reg., Missoula, Mont.

The report discusses the uses of meteorological prediction models in planning and conducting aerial spray operations with insecticides. The presentation includes a discussion of model inputs and calculations for the 1974 Idaho tussock moth test for determining spray drop-size distribution and spray deposition and concentration at the forest canopy.
Control - 7

67. Eaton, C. B., and G. R. Struble. 1957. The Douglas-fir tussock moth in California. Pan-Pac. Entomol. 33(3):105-108.

Reappraisal of the *Hemerocampa* species attacking fir indicates that the tussock moth periodically defoliating white fir in California is *Hemerocampa pseudotsugata* McDunnough. It had been misidentified in that state as *H. oslari* (Barnes) for nearly 50 years. The identification of specimens collected in 1906 in Mariposa Co. as *H. pseudotsugata* extends the known range of the Douglas-fir tussock moth to northeastern California.

White fir is the primary host of the Douglas-fir tussock moth in California. It has not been recorded from Douglas-fir. Local outbreaks have periodically occurred in the northern Sierra Nevada but with less severity than in other states.
Taxonomy; Host Relationships - 1

68. Edwards, S. K. 1965. Activity rhythms of lepidopterous defoliators. III. The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Liparidae). Can. J. Zool. 43(5):673-681.

This is an extension of earlier work on activity rhythms of lepidopterous defoliators to the Douglas-fir tussock moth. Time of eclosion, larval activity on foliage, adult emergence, and flight were recorded in constant and naturally varying temperature and light regimes.

Egg hatch peaked after the sunrise transition, tapering off as the day progressed. Hatching time apparently did not respond to variation in temperature.

Young larvae were active throughout the day at temperatures above 20°C, but only diurnal activity persisted at a constant temperature of 10°C. Feeding periods paralleled activity.

The dropping of young larvae was timed more by light than by temperature. Two peaks occurred, one after sunrise and another in the

afternoon. The position of the afternoon peak was influenced by temperature.

Late-instar larvae were mainly nocturnal in the constant and varying temperature regimes, and defoliation occurred at night.

Adult emergence and flight of males was greatest about 4 hr before sunset, and there was evidence of mating at the same time of the day. Heightened activity at this time of the day was detected as early as the 1st- and 2nd-instar larvae.

"The possible adaptive value of these rhythms in the insects in nature is discussed."
Biology - 1

69. Elgee, E. 1975. Persistence of a virus of the white-marked tussock moth on balsam fir foliage. Can. For. Serv. Bi-Mon. Res. Note 31(5):33-34.

Results of a study of the persistence of nucleopolyhedrosis virus, which under natural conditions has terminated infestations of the white-marked tussock moth, *Orgyia leucostigma* (J. E. Smith), in Nova Scotia are reported.

Tests were conducted on balsam fir foliage contaminated either by virus residues of the white-marked tussock moth or spray applications of virus suspensions. The relation between the strength of the suspension and virus persistence to exposure was also studied.

"Results suggest that the virus, deposited on the foliage (naturally or artificially) in the summer, retains sufficient activity through the winter to kill at least some larvae, and that spraying, even when done the previous year, increases larval mortality." Exposure of contaminated foliage to sunlight, precipitation, or both reduces virus activity. "The rate of inactivation depends on the degree of exposure of the branches to

weathering and the period to inactivation depends both on the strength of the suspension and the degree of exposure of the branches to weathering."
Related Material - 3

70. Ellefson, P. V. 1974. Douglas-fir tussock moth infestation: a challenge to forestry professionals. J. For. 72(6):326-327, 329.

The paper presents a discussion of the Blue Mountain Douglas-fir tussock moth outbreak (1972-1974), the extent of the present damage, its economic impact, and the alternatives available for control. The USDA Forest Service requested emergency exemption from the EPA ban on DDT, both in 1973 and 1974. In 1974, the EPA granted the exemption provided certain conditions be met before DDT application and that surveys reveal populations capable of causing significant damage if left uncontrolled. Spraying had to be conducted according to certain restrictions established to minimize environmental contamination. The Forest Service control plan is briefly outlined.
Outbreaks - 2; Control - 4

71. Environmental Protection Agency. 1973. The Douglas-fir tussock moth in the Pacific Northwest. A seminar sponsored by the U.S. EPA Washington, D.C. 105 p. Unpubl. (On file: Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg.)

The texts of the addresses given at a seminar on the current Douglas-fir tussock moth pest situation in the Pacific Northwest are presented. The objective of the seminar was to bring together experts from the Federal, State, academic, industrial, and environmental agencies to explore the technical problems and research needs in tussock moth control.

The morning session concentrated on discussions of the current status of the tussock moth outbreaks in Oregon and Washington, the state of present knowledge of tussock moth biology and outbreak cycles, and present strategies for control.

The afternoon session centered on research needs, both in the areas of tussock moth biology and control procedures for outbreak populations.
General Background; Related Material - 2

72. Environmental Protection Agency. 1974. The use of DDT to control the Douglas-fir tussock moth. Fed. Regist. 39(44):8377-8380.

The paper concerns the decision of the EPA on requests of the USDA Forest Service and the States of Oregon and Washington for exemption of the prohibition against the use of DDT to control potential emergency outbreaks of the Douglas-fir tussock moth. Requests were made pursuant to section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act.

The paper reviews the background leading to the requests, the biology of the Douglas-fir tussock moth, the status of the current outbreak and its possible economic impact, possible alternative control methods, and the legal and economic factors underlying the decision of the EPA.

The reasons for granting the exemption to the Forest Service and not to the States of Oregon or Washington, along with the restrictions and requirements accompanying the exemption, are outlined.
Control - 4

73. Eslyn, W. E. 1959. *Hemerocampa pseudotsugata* McDunnough, a new host for *Beauveria bassiana* (Balsamo) Vuillemin. J. Insect Pathol. 1(4):434-435.

Mummified pupae of the Douglas-fir tussock moth containing mycelial growth of the fungus *Beauveria bassiana* (Balsamo) Vuillemin were found under rocks in the Lincoln National Forest, New Mexico, in March 1959. This is a new host record for the fungus. The physical characteristics of the fungus are described. Its possible use in biological control of the Douglas-fir tussock moth is suggested.
Biology - 4

74. Evenden, J. C. 1948. An epidemic of the Douglas-fir tussock moth. Northwest Sci. 22(2):53-59.

This is a brief summary of the 1946 and 1947 reports by the author on the Douglas-fir tussock moth outbreak in northern Idaho and the aerial application of DDT used to control the problem. The paper includes a description of the moth, its means of dissemination, and a brief history of tussock moth epidemics in the Northwest.

The tussock moth epidemic in northern Idaho, the largest ever recorded, is described. By 1946, 350,000 acres were infested and 150,000 were severely defoliated. Surveys in 1946 predicted even greater populations of the tussock moth for 1947.

Aerial application of DDT was timed to effect maximum kill of young larvae and minimum disruption of predacious and parasitic insect populations. A study by the U.S. Fish and Wildlife Service on the environmental impact of DDT showed damage only to some forms of aquatic life.

Larval mortality near 100% was reported.
Outbreaks - 2; Control 2, 3

75. Evenden, J. C., and E. J. Jost. 1946. An outbreak of the Douglas-fir tussock moth (Hemerocampa pseudotsugata) in Latah and Clearwater Counties, Idaho, 1946, a report. USDA Bur. Entomol. and Plant Quar., Intermt. For. and Range Exp. Stn., Missoula, Mont. 22 p. Unpubl.

This report is on the 1946 Douglas-fir tussock moth outbreak in northern Idaho. The study was conducted by the Forest Insect Laboratory at Coeur d'Alene, Idaho, under the direction of the Bureau of Entomology and Plant Quarantine and the USDA Forest Service. The entomological, physical, and economic factors associated with the infestation were evaluated to determine the advisability of control measures. The report

includes a description of the Douglas-fir tussock moth, its seasonal history, and habits.

A survey of the area showed the tussock moth present in about 447,000 acres, and severe defoliation occurred in 150,000 acres. Estimates of the potential 1947 population from studies of egg masses in the field indicated an even greater number of larvae than in 1946. Aerial application of chemical control was recommended. The feasibility of aerial spraying was examined in detail. The entomological, environmental, economic, and social impact of the use of DDT for this control project were explored.
Outbreaks - 2

76. Evenden, J. C., and E. J. Jost. 1947. Tussock moth control, north Idaho, 1947, a report. Intermt. For. and Range Exp. Stn., Missoula, Mont. 28 p. Unpubl.

A detailed report of the organization, methodology, and results of the aerial application of DDT conducted in the spring of 1947 against a serious outbreak of the Douglas-fir tussock moth in northern Idaho. The project, the largest of its kind to date, was conducted with the cooperation of private, State, and Federal timber owners under the direction of the USDA. The Forest Service supervised the fiscal and administrative details and the Bureau of Entomology and Plant Quarantine directed the technical aspects.

DDT was sprayed on 413,469 acres of land. Larval mortality was near 100%. The U.S. Fish and Wildlife Service conducted a survey on the environmental effects of the spray application. Only damage to some aquatic forms was reported.

An appendix includes typical field forms and a photographic summary of the project.
Control - 2, 3

77. Evergreen State College. 1973. Douglas-fir tussock moth in the Northwest: The case against DDT use in 1974. Ecology and chemistry of pollution, Olympia, Wash. 25 p. Unpubl. (On file: Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg.)

An analysis of the status of the Douglas-fir tussock moth outbreak in the Blue Mountains, 1972-1974, and the case against the use of DDT for tussock moth control are presented in a series of papers by members of the Evergreen State College.

The first paper charges that the forest products industry has distorted the situation in their request for use of DDT for tussock moth control. The remaining papers examine each of the alleged distortions and present a detailed rebuttal.

Control - 4

78. Family Tree. 1947. Operation flit gun. Family Tree 11(9), 3 p.

A popular account is given of a control project using DDT for control of the tussock moth. A 300,000-acre infestation was sprayed in 1947. Mortality of tussock moth larvae was considered excellent.

Control - 2

79. Flake, H. W., and R. L. Lyon. 1967. Insecticide tests against larvae of _Hemerocampa_, new species, a tussock moth that defoliates boxelder in New Mexico. J. Econ. Entomol. 60(2):607-608.

Six insecticides were selected for preliminary laboratory testing against _Hemerocampa_, n. sp., larvae, a nuisance pest in 1965 on boxelder, _Acer negundo_ L., in southwestern New Mexico. Testing took place in the laboratory in an attempt to find an insecticide suitable for field use. Egg masses were collected and shipped to the laboratory at Berkeley, California. The larvae were reared to 5th instar, and were held during and after treatment in groups of 10. "Larvae were treated individually by applying to the prothoracic region a 1-µl drop of an acetone-insecticide

solution." Pyrethrin, Zectran®, p, p'-DDT, carbaryl, and SD-8530 were sufficiently active to merit additional tests. The insects were highly tolerant to malathion.
Related Material - 3

80. Forestry Research News. 1974. Forest Service reports results of tussock moth research. . . . Several alternatives to DDT appear promising. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. 5 p. Unpubl.

The highlights of research in 1974 on the Douglas-fir tussock moth are given. "The studies have generally supported the theory of a 3-year cycle between outbreak and decline of tussock moth epidemics, substantiate the effectiveness of DDT in controlling epidemics, and show promise for several chemical and biological alternatives to DDT." Other findings were that "tree mortality and damage were strongly related to the percentage of Douglas-fir in the infested stands, with Douglas-fir hit harder than other species." Trees defoliated in the Blue Mountains were beginning to "green up" and recover.
Control - 1; Related Material - 2

81. Forestry Research, What's New in the West. 1974. A virus that kills tussock moths. USDA For. Serv., p. 4-5, 12-13.

The research by the USDA Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon, to develop microbial control methods against the Douglas-fir tussock moth, is outlined. Both Bacillus thuringiensis and the tussock moth nucleopolyhedrosis virus have been tested with good results. The virus is especially promising as a control agent. Tests for its impact on nontarget organisms have thus far proved negative. Future plans for additional virus field tests are briefly outlined.
Biology - 5, Control - 6

82. Furniss, M. M., and J. A. E. Knopf. 1971. Western tussock moth. USDA For. Serv. For. Pest Leafl. 120, 4 p.

A subspecies of the western tussock moth, Orgyia vetusta gulosa (Boisd.) = (Hemerocampa) is an important defoliator of big game browse plants and fruit trees. The moth occurs in the northwestern United States and in Canada. The appearance of the different stages and the life cycle of the moth are described. Natural enemies of the tussock moth include eight parasites, two predators, and a polyhedral virus. Parasites and predators have reduced the population by 50% in citrus groves and apple orchards. In Idaho, the virus has controlled moth outbreaks.

Related Material - 3

83. Gay, R. L. 1973. Douglas-fir tussock moth infestation in Oregon. An environmental dilemma of national importance. OSPIRG Reports (April), Portland, Oreg. 34 p. Unpubl. (On file: Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg.)

The report presents a detailed case against the USDA Forest Service request for emergency use of DDT to control the Douglas-fir tussock moth outbreak in the Blue Mountains in 1973. Results of OSPIRG research are given to support the contentions that (1) State and Federal forest officials have failed to show that any chemical control is needed, and (2) Zectran is a feasible alternative to DDT should chemical control be necessary. The report contends that (1) the Forest Service estimates of potential defoliation in 1973 were calculated by questionable means, using a defoliation formula without a quantitative basis; (2) the survey technique used to sample populations failed to distinguish properly among populations capable of causing heavy, intermediate, or light damage; and (3) the Forest Service evaluation of Zectran did not accurately reflect its efficacy as an alternative to DDT. Field tests show that Zectran has the necessary toxicity to accomplish high population reduction, especially when applied twice.

The report recommends that resampling should be done to determine if signficant tree mortality will be caused by tussock moth larvae in 1973. If these populations exist, salvage logging should be the first preference

as a control measure. If chemical control must be used, Zectran should be applied.
Control - 4

84. Getzendaner, C. W. 1966. Study of methods and materials for evaluating virus spray deposits. Part IV. In Results of tests to develop operational procedures for controlling Douglas-fir tussock moth with aerial application of polyhedral virus spray. USDA Agric. Res. Serv. and For. Serv., Portland, Oreg. 19 p. Unpubl.

"The fourth phase of cooperative virus spray studies was conducted in June 1965 on the Mt. Hood National Forest, Oregon, in conjunction with phase-two investigations. Objectives were to (1) evaluate the use of fluorescent tracer for assessing aerial spray deposits under forest conditions, (2) determine spray distribution patterns and droplet sizes from the equipment used, and (3) compare the efficiency of various sampling surfaces for determining spray deposits.

"The fluorescent tracer, Calcofluor® white, when used with suitable recovery targets, proved to be a useful material for evaluating spray patterns, distribution, droplet size, and foliage penetration. . . . Spray applied at 1 gal per acre deposited droplets of much more uniform size than applications at 3 gal per acre. . . . Kromekote® paper cards were better than other target materials for visual evaluation of both fluorescent and dye-tagged sprays. Stainless steel plates were best for quantitative measurement of dye-tagged sprays. . . . The Calcofluor white tracer maintains its stability and fluorescence on foliage for long periods if kept dry. It has shown no appreciable deterioration after storage for nearly a year under normal conditions."
Control - 9

85. Gibney, L. C. 1974. The plight of the tussock moth. Environ. Sci. Tech. 8(6):506-507.

A brief overview of the tussock moth problem including the life cycle of the moth, its status as a pest, and a history of tussock moth infestations in the Northwest.

The conditions and restrictions accompanying the 1974 decision by the EPA to grant to the USDA Forest Service an emergency exemption from the prohibition on the use of DDT in tussock moth control are summarized. An egg mass density of one-tenth egg mass per 1,000 in^2 of foliage will be required to establish economic injury. The paper includes a diagram of the fate of DDT in the environment after spraying.

The need for alternative means of control is stressed.
Control - 4

86. Gibson, A. L., and T. T. Terrell. 1955. Preliminary report of Douglas-fir tussock moth infestation in northeastern Washington. USDA For. Serv. Intermt. For. and Range Exp. Stn., Missoula, Mont. 3 p. Unpubl.

A preliminary examination of reported Douglas-fir tussock moth infestations in northeastern Washington was conducted June 27-29, 1955, by members of the Forest Insect Laboratory, Missoula, Montana, at the request of the Pacific Northwest Forest and Range Experiment Station. Infestations occurred in several scattered areas with damage ranging from single trees to 20-acre stands.

The report lists possible control measures and recommended implementation before pupation commenced. Monitoring of present infestation sites was recommended. A second survey was planned by members of the laboratory in late August or September, to determine evidence of expansion of the infestation to intervening stands.
Outbreaks - 2

87. Grace, T. D. 1958. Induction of polyhedral bodies in ovarian tissue of the tussock moth in vitro. Science 128(3318):249-250.

"In a series of experiments primarily set up to test the effects of various concentrations of Eagle's basal medium on the growth of the ovarian tissue of the tussock moth (Hemerocampa leucostigma), polyhedral bodies appeared in some of the cultures after a change was made in the media used. . . . The tissues were obtained from last instar larvae growing on sycamore trees. . . . On gross and microscopic examination, both before and after dissection, no evidence of infection was seen in any of the larvae used. Explants were chosen at random when the cultures were set up. No evidence of infection was noticed in any culture before the change of medium. Only those cultures in which the medium was changed showed infection."

The author postulates "that the larvae used in this experiment carried a latent infection of a polyhedrosis which became manifest after the cultures were subjected to a 'physiological shock' brought about by an abrupt change from one medium to another."
Related Material - 3

88. Graham, D. A. 1972. Testing of improved insecticides for forest pest management. USDA For. Serv. Fact Sheet, Reg. 6, Portland, Oreg. 8 p. Unpubl.

The paper outlines a proposed test of stabilized pyrethrins and Zectran for suppression of the Douglas-fir tussock moth outbreaks. It includes a description of the insect and its life cycle, its status as a pest, a brief history of severe epidemics in the Northwest, and a review of the current outbreaks in central Washington. The possibilities of biological control are outlined.

The report provides background information on toxicity, persistence of breakdown products, and potential hazards of pyrethrins and Zectran. Both insecticides will be given in two applications 10 days apart to ensure the mortality of those larvae emerging after the first treatment. Stabilized pyrethrin at 0.05 lb/acre and Zectran at 0.15 lb/acre will be applied to two 400-acre plots in the infested area of central Washington.

Test plots within the spray areas will be evaluated for pre- and posttreatment larval populations, defoliation occurring in July of 1972 and 1973, and number of egg masses present in October 1972.
Control - 1

89. Graham, D. A. 1975. Douglas-fir tussock moth 1974 operational spraying of DDT. West. For. Conserv. Assoc., Perm. Assoc. Proc. 1974:21-23. Portland, Oreg.

This is the text of an address to the association on the successful 1974 control of the Douglas-fir tussock moth epidemic in the Northwest. Background information is presented on the beginning of the outbreak in 1970, the extent of damage in 1972 and 1973, the search for alternate means of chemical control, and the unsuccessful attempt in 1973 to secure exemption from the EPA ban on the use of DDT. Details of the 1974 effort, which resulted in permission for the temporary use of DDT, are given. The control operation, its personnel, organizational structure, and methods of operation are summarized; 570 people worked on spraying 426,559 acres with DDT at a cost of $2,900,000. Resulting insect mortality was 97% in all areas with the exception of a small area in southern Idaho. The use of DDT despite a predicted population decline in 1975 from natural causes is rationalized on the basis of prevention of the potential damage of the current year's larval population.
Control - 2, 4

90. Graham, D. A., J. Mounts, and D. Almas. 1975. 1974 cooperative Douglas-fir tussock moth control project, Oregon, Washington, and Idaho. USDA For. Serv. Pac. Northwest Reg., Portland, Oreg. 74 p. Unpubl.

This report covers the 1974 Douglas-fir tussock moth control project in the Northwest. Between June 9 and July 25, 426,559 acres of forest land in Oregon, Washington, and Idaho were treated with DDT at 0.75 lb/acre. Application was by helicopter. The background of the Douglas-fir tussock moth infestation, the biology of the moth, and the

biological evaluation of the outbreak population were discussed. DDT was the only chemical that had previously proved to be effective. Although several other chemical and microbial agents had been tested against the tussock moth, the results were not satisfactory or additional large-scale testing was required.

The planning and preparation of the control project, the details of the spray operation, the surveys for insect mortality, the environmental monitoring plans, and the estimates of foliage and timber values saved by the control project were presented. The average postspray mortality of larvae was 98.8%. The control project was evaluated as highly successful.
Control - 2, 3

91. Graham, F., Jr. 1974. The return of DDT - pest control by press release. Audubon 76(5):64-71.

A detailed analysis is presented of the controversy surrounding the USFS request for emergency use of DDT to control the Douglas-fir tussock moth outbreak in the Pacfic Northwest (1972-74).
Control - 4

92. Graham, F., Jr. 1975. Update: moths and DDT. Audubon 77(2):120-121.

An analysis is presented of the controversy surrounding the aerial application of DDT to control the Douglas-fir tussock moth in the Pacific Northwest. The environmental impact of the spray control project is also examined.
Control - 4

93. Grant, G. G. 1975. Extraction and bioassay of the female sex pheromone of white-marked tussock moth, Orgyia leucostigma (Lepidoptera: Lymantriidae). Can. Entomol. 107(3):303-309.

"Factors affecting the extraction and bioassay of the sex pheromone of white-marked tussock moths were evaluated. Dipping the female

pheromone glands in a solvent (preferably hexane) to produce a wash containing active material was a particularly effective and reproducible method of obtaining a potent extract. These were most active if obtained from virgin females less than 2 days old. Extracts from recently mated females were only slightly less active than those from virgin females. Males were most responsive in bioassays when 2 to 3 days old. The maximum percentage of response of males was obtained at $1X10^{-4}$ FE (female equivalents); beyond this concentration the percentage response decreased. Characteristically, extracts lost their potency within 1-3 weeks of preparation. It is suggested that either an inhibitor or the loss of a chemical component of the sex pheromone causes an extract to become inactive."

Related Material - 3

94. Grant, G. G. 1977. Interspecific pheromone responses of tussock moths and some isolating mechanisms of eastern species. Environ. Entomol. 6(5):739-742.

"Laboratory tests with 5 species of Orgyia tussock moths (O. leucostigma (J. E. Smith). O. definita Packard, O. antiqua (L.), O. pseudosugata (McDunnough), and O. cana (=vetusta) Edwards) revealed that all species show some degree of pheromone cross stimulation which ranged from weak (16-41% response) to strong (60%). O. definita showed the most exclusive sex pheromone system because they were strongly stimulated by fewer species and only homospecific males responded strongly to definita females.

"In the laboratory, (Z)-6-heneicosen-11-one, the female sex pheromone of O. pseudotsugata, was sexually stimulating to O. leucostigma and O. antiqua males but not to O. definita males. In electroantennogram tests, O. definita males were 100-fold less sensitive than the other 2 species to this compound. In the field, the chemical attracted O. leucostigma, O. antiqua, and the pine tussock moth, Dasychira plagiata (Walker). Several isolating mechanisms were described which help maintain the species integrity of these sympatric eastern tussock moth species."

Biology - 2, Related Material - 3

95. Grant, G. G., and D. Frech. 1976. Mating disruption of tussock moths by atmospheric permeation with synthetic sex pheromone. Can. For. Serv. Bi-Mon. Res. Notes 32(5):25-26.

The six pheromone of the Douglas-fir tussock moth can sexually stimulate and attract males of the white-marked tussock moth (O. leucostigma) and the rusty tussock moth (O. antiqua). Laboratory experiments were conducted to determine if large concentrations of the Douglas-fir tussock moth sex pheromone can disrupt the mating ability of these species. Four other compounds were tested, including disparlure, the sex pheromone of the gypsy moth. Reduction in mating in the white-marked tussock moth was linearly related to the dosage of tussock moth pheromone used. Percent mating reduction after 6 hr ranged from 34% with 0.1 µg pheromone, to 82% for 100 µg. The mating reduction in the rusty tussock moth was 70% for 100 µg pheromone after 6 hr. Of the four other chemicals tested, only disparlure caused a statistically significant reduction in the white-marked tussock moth mating after 24 hr.
Biology - 2; Related Material - 3

96. Grant, G. G., D. Frech, and D. Grisdale. 1975. Tussock moths: pheromone cross stimulation, calling behavior, an effect of hybridization. Ann. Entomol. Soc. Am. 68(3):519-524.

"Adult crosses, pheromone extract bioassays, and electroantennogram (EAG) tests suggest that three species of tussock moth, Hemerocampa leucostigma (J. E. Smith), H. pseudotsugata McDunnough and H. vetusta (Boisduval), have similar sex pheromones. The same tests also indicate that hybrids from the cross female H. pseudotsugata x male H. leucostigma possess a sex pheromone system more like the female parent than the male parent; that is, the sex pheromone of the female hybrid was like that of female H. pseudotsugata, and the pheromone receptors of the male hybrid were like those of male H. pseudotsugata. On the other hand, the calling periodicity of female hybrids displayed traits of both parents." Most of the males attempted copulation with females of other species, but few

were successful. Differences between pheromones and male sensitivity of the three species and hybrid are discussed.
Biology - 2; Related Material - 3

97. Grant, G. G., and L. McCarty. 1977. Effect of age on calling behavior and mating success of white-marked tussock moths. Can. For. Serv. Bi-Mon. Res. Notes 33(1):2-3.

Described are several factors related to aging that affect mating and fecundity in the white-marked tussock moth, Orgyia leucostigma J. E. Smith. At emergence, the females are ready to mate and contain a full complement of mature eggs. Successful mating is reduced with increasing time after eclosion. Only 33% of 2-day-old females mated in one overnight period, compared to 83% of newly emerged females in the same period.

Decreased mating success of older virgin females is related to decreased pheromone production and decreasing female attractiveness. The pheromone releasing mechanism (i.e., calling behavior) is altered and replaced by oviposition behavior (egg spewing) in older virgin females.

Records of number of eggs deposited by virgin females and percentages of the females calling showed a progressive decline in calling behavior over time as egg deposition increased. Thus the consequence of aging in white-marked tussock moth females is a decreased chance of successful mating.
Related Material - 3

98. Grau, P. A. 1974. Mixing and formulation of Bacillus thuringiensis. In Aerial application of insecticides against forest defoliators (chemicals and microbials). Proceedings of workshop held April 23-25, 1974, Univ. Mont., Missoula, p. 21-26. USDA For. Serv., State and Private Foresty, Northern Region, Missoula, Mont.

This discussion concerns the type of equipment available for mixing Bacillus thuringiensis wettable powders, the effect of storage on the viability of mixed formulations, and the types of additives used in tank mixes and their effect on the residual effectiveness of B.t. in the field. Included is a general review of B.t. and its toxic properties; the formulation Dipel to be used in the Douglas-fir tussock moth control project; and a table on the effects of simulated rainfall on spray-deposit retention of various formulations of Dipel.
Control - 8

99. Grisdale, D. G. 1975. A simple method for removing pupae from cocoons. Can. For. Serv. Bi-Mon. Res. Notes 31(2):9.

The paper describes a method of removing pupae of Malocosoma disstria and Orgyia spp. from cocoons that avoids the allergic responses to larval hairs and parts of the cocoon. Washing the cocoons in a solution of bleach containing 6% available sodium hypochloride dissolves the cocoon silk. After being rinsed in a water bath, the pupae are placed in a screen box and rinsed free of debris. About 2,000 pupae can be separated from their cocoons in 1/2 hr without adverse effects on the future adult moths.
Biology - 6

100. Grissell, E. E. 1973. New species of North American Torymidae (Hymenoptera). Pan-Pac. Entomol. 49(3):232-239.

The description of four new species of Torymidae is presented. They are: Monodontomerus saltuosus Grissell, reared from the Douglas-fir tussock moth; M. clementi Grissell, reared from an anthidiine bee; Torymus frankiei Grissell, reared from a cecidomyiid gall; and T. memnonius Grissell, from a cynipid gall.

The holotype, allotype, and some paratypes will be deposited in the U.S. National Museum. Paratypes will be located in the Canadian National Collection, Ottawa, and the Entomology Museum, U. C. Davis.
Biology - 3

101. Hafez, M., and L. El-Said. 1969. On the bionomics of Orgyia dubia judaea Stgr. (Lepidoptera: Lymantriidae). Bull. Soc. Entomol. Egypt. 53:161-183.

Orgyia dubia judaea Stgr. is found abundantly on wild plants growing on saline soil near the northern coast in U.A.R. The insect can be reared on clover and sweet potatoes. The authors fear that it may become an economic pest. The morphology of all the stages is discussed in detail. Eggs are deposited inside the female cocoon. The species is univoltine. Six species of primary parasites and one species of secondary parasite were captured during the study.
Related Material - 3

102. Hall, D. G. 1947. Tussock moth hits Idaho. Timberman 48(6):46-48.

A popular account is given of a tussock moth outbreak near Moscow, Idaho. The population was expected to increase and infest 350,000 acres during 1948. Control operations using DDT were expected to be undertaken by June 1948.
Outbreak - 2

103. Hard, J. S., J. D. Ward, and S. Ilnytzky. 1977. Douglas-fir tussock moth control on Douglas-fir, 1976. Insectic. and Acaricide Tests 2:113.

Dimilin was applied at three different rates against epidemic Douglas-fir tussock moth populations near Kamloops, B.C. All three Dimilin treatments gave significant control at 35 days, with the greatest mortality occuring from the 2 oz/acre dosage.
Control - 1

104. Harper, J. D. 1974. Forest insect control with Bacillus thuringiensis. Survey of current knowledge. Agric. Exp. Stn., p. 32-34. Auburn Univ., Auburn, Ala.

This chapter discusses the history of control of the Douglas-fir tussock moth with Bacillus thuringiensis, the reasons for success or failure of control projects, and the conditions needed for reproducible control levels of 95% or higher. "Larvae treated in the second or third instar, and large droplet size combined with high droplet density" have produced the best results.
Control - 5

105. Harwood, R. F. 1975. Economics, esthetics, environment, and entomologists: The tussock moth dilemma. Environ. Entomol. 4(2):171-174.

"The author reviews the life cycle and impact of Hemerocampa pseudotsugata McDunnough, and the variety of known and assumed factors involved in the decision to use DDT during 1974 to control the outbreak in Washington, Idaho, and Oregon. Potential alternative control procedures are listed. While the issue is complicated, fault is found in the response of agencies, environmentalists, and entomologists to the serious threat presented by this extensive outbreak of the tussock moth."
Control - 4

106. Hayashi, Y. 1970. Properties of RNA from cytoplasmic-polyhedrosis virus of the white-marked tussock moth, Orgyia leucostigma. J. Invertebr. Pathol. 16(3):451-458.

"When the genome RNA is extracted from the cytoplasmic-polyhedrosis virus of the white-marked tussock moth, Orgyia leucostigma, by the phenol method, it has two components with sedimentation rates of about 15 and 12 S. Their base composition includes adenine and uracil as well as guanine and cytosine. The guanine plus cytosine content was 41.2 percent. Melting temperature of the RNA was about 80°C. in a solution containing 0.0015 M NaCl - 0.00015 M sodium citrate. Most of the RNA was found to be resistant to ribonuclease digestion; some of it was partially sensitive and was presumed to be single-stranded. After enzyme treatment, the 15 and 12 S components of the genome sedimented at about 9 S. From these

findings it is proposed that viral genome RNA from cytoplasmic-polyhedrosis virus is double-stranded."
Related Material - 3

107. Hayashi, Y., and F. T. Bird. 1970. The isolation of cytoplasmic polyhedrosis virus from the white-marked tussock moth, Orgyia leucostigma (Smith). Can. J. Microbiol. 16(8):695-701.

"The procedure for isolating and purifying free and occluded cytoplasmic polyhedrosis virions was improved. The virions are resistant to the enzymes RNase, DNase, trypsin, chymotrypsin, and phospholipase C, and to a detergent, deoxycholate. The use of these enzymes and deoxycholate, in combination with discontinuous and linear sucrose gradients, produced very pure preparations of free virions. Occluded virions were released by dissolving polyhedra in 0.05 M Na_2CO_3 - 0.04 M NaCl for 60 min at room temperature. The composition of the virion was estimated to be about 28% RNA and 72% protein."
Related Material - 3

108. Herman, S. G. 1975. The Douglas-fir tussock moth DDT application of the summer of 1974: Effects of the DDT on nontarget organisms and residue accumulation in vertebrate animals. A progress report-Feb. 1975. West. For. and Conserv. Assoc., Perm. Assoc. Comm. Proc. 1974:18-21. Portland, Oreg.

During a broadly based environmental monitoring program, 13 persons from the Evergreen State College studied DDT residues from the 1974 Douglas-fir tussock control project in the Blue Mountains. Sampling occurred from May 17 to August 7. Plots were set up in spray and nonspray areas. Sampling for aquatic insects showed that where a buffer zone was left adjacent to the stream within the spray areas, stream insects were little affected. One stream that was directly sprayed had no insect life for a month afterward. Arboreal insects, particularly parasitic wasps and flies, showed a drastic population reduction. One stream had a large number of dead sculpin after the spray. Results on small mammal

populations were inconclusive. Counts of passerine birds showed a 24-54% decline after spraying. Brain samples from dead birds showed that death was caused by DDT poisoning. DDT residues increased in all vertebrates studied.
Control - 3

109. Hewson, R., and D. K. Mardon. 1970. Damage to heather moorland by caterpillars of the vapourer moth Orgyia antiqua L. (Lep., Lymantriidae). Entomol. Mon. Mag. 106:82-84.

The vapourer moth is well distributed throughout Britain and occasionally causes damage of commercial importance. A survey was made of an outbreak of damage to heather moorland in 1969. The number of caterpillars, cocoons, and egg masses were counted, and an estimate of defoliation was made. Vaccinium was the preferred food plant. The heather was burned the following year, and the infestation spread to a nearby pine and larch plantation, where the larvae caused some damage.
Related Material - 3

110. Hicks, M. E., D. Swanger, R. E. Pacha, and A. R. Tiedemann. 1976. The effect of the Douglas-fir tussock moth deforestation on microbiological and chemical water quality of damaged watersheds. (Abstr.) Am. Soc. Microbiol., Northwest Branch.

"An assessment of the impact of the insect-caused deforestation on microbiological and chemical water quality parameters was conducted on damaged watersheds, with and without salvage logging, and adjacent unaffected areas."
Outbreaks - 5

111. Hicks, M. E. 1977. Effect of deforestation by the Douglas-fir tussock moth on the quality of streamflow and stream productivity parameters. M.S. thesis. Cent. Wash. State Coll., Ellensburg. 104 p. (No copies available.) Unpubl.

"Seven watersheds of three types were examined to determine if deforestation by the Douglas-fir tussock moth and subsequent salvage logging had any effect on stream water quality. Results indicate only seasonal fluctuations and differences among watersheds due to inherent properties of individual watersheds. Increased turbidity levels were detected on logged watersheds which could be correlated with the logging activities."
Outbreaks - 5

112. Hughes, K. M. 1957. An annotated list and bibliography of insects reported to have virus diseases. Hilgardia 26(14):597-629.

Of the lymantriid moths listed, Hemerocampa leucostigma and H. pseudotsugata are listed as having a polyhedrosis virus.
Biology - 5; Related Material - 3

113. Hughes, K. M. 1972. Fine structure and development of two polyhedrosis viruses. J. Invertebr. Pathol. 19(2):198-207.

"Some characteristics of two viruses of the Douglas-fir tussock moth are described. Viral development appears to start in the nuclei of infected cells with the formation of tubes believed to be capsids. Subsequently, the tubes are filled with viral nucleoprotein. Filaments that may be molecules of DNA are illustrated. Objects believed to be defective virus particles, consisting of capsids that contain a subnormal quantity of nucleoprotein, are described. The bearing of these observations on the existence of an 'intimate membrane' is discussed."
Biology - 5

114. Hughes, K. M. 1976. Notes on the nuclear polyhedrosis viruses of tussock moths of the genus Orgyia (Lepidoptera). Can. Entomol. 108(5):479-484.

"Three western species of tussock moths of the genus Orgyia are all susceptible to infection by the same two nuclear polyhedrosis viruses.

An eastern species of Orgyia is also affected by these viruses. In the western states, the natural occurrence of the two viruses appears to be limited to definite geographic areas. Infectivity of the viruses for hosts outside the genus Orygia is not known. One report of such cross-infectivity could not be substantiated. Bodies which appear to be composed of viral materials but which are not normal virus particles are sometimes found occluded in polyhedra."
Biology - 5; Related Material - 3

115. Hughes, K. M., and R. B. Addison. 1970. Two nuclear polyhedrosis viruses of the Douglas-fir tussock moth. J. Invert. Pathol. 16(2):196-204.

"Two nuclear polyhedrosis viruses affecting the Douglas-fir tussock moth, Hemerocampa pseudotsugata, are described. One induces formation of polyhedral bodies containing single rod-shaped virus particles, each within its own envelope. The other produces polyhedra with bundles of several rods within a common envelope. The same tissues of the host are affected by both viruses, although not equally. Mean lengths of the rods of the two types differ. One type of virus has been found in only a few geographic locations." After three passages of each virus through insects, no reversion to the alternate type was observed.
Biology - 5

116. Ilnytzky, S., J. R. McPhee, and J. C. Cunningham. 1977. Comparison of field-propagated nuclear polyhedrosis virus from Douglas-fir tussock moth with laboratory produced virus. Can. For. Serv. Bi-Mon. Res. Notes 33(1):5-6.

A nuclear polyhedrosis virus from the white-marked tussock moth, Orgyia leucostigma (J. E. Smith), was propagated in the field (Kamloops, B.C.) using 36 Douglas-fir trees infested with a population of 30-150 larvae of the Douglas-fir tussock moth, Orgyia pseudotsugata (McD.). Larvae were infected in the 4th and 5th instars. The first recorded deaths occurred 10 days after virus spray application. On the 14th day postspray, 7,000 larvae were shaken from the trees and processed, yielding 188 g of powder with 4 billion polyhedra/g.

The field-propagated virus was tested against the laboratory-produced virus (propagated on white-marked tussock moth) on 2-ha plots infested with Douglas-fir tussock moth larvae. Two aerial sprays produced an application rate of 125 billion polyhedra/ha.

Comparisons between pre- and postspray larval populations showed similar mortality rates for both field- and laboratory-propagated virus preparations and that control could be obtained from the 125 billion polyhedra/ha dosage.

The advantages and disadvantages of field- and laboratory-propagation methods are discussed.
Control - 6

117. Interagency Tussock Moth Steering Committee. 1973. The Douglas-fir tussock moth problem in the Northwest. Status, impacts, and alternatives for 1974. Portland, Oreg. 18 p. Unpubl.

An informal question-and-answer format is used to inform the public concerning the status of the Douglas-fir tussock moth outbreak in the Northwest, which began in 1972. Maps and tables of areas of defoliation and proposed treatment sites are presented. The alternatives for control are explained along with the rationale for the use of DDT and its possible impact on the environment. Criteria for control recommendations are outlined. The assessment of actual need for control in 1974 must await the results of the USDA Forest Service laboratory report in March on the natural virus levels in egg masses and the effects of predators, parasites, and overwintering stress on larval emergence.
Control - 4

118. Iwai, P. J., and M. E. Martignoni. 1975. Preparation of suspensions of nucleopolyhedrosis virus of the Douglas-fir tussock moth for field application. In Aerial application of insecticides against forest defoliators (chemicals and microbials). Proceedings of workshop held April 23-25, 1974, Univ. Mont., Missoula, p. 19-20. USDA For. Serv., State and Private Forestry, Northern Region, Missoula, Mont.

A description of the preparation of suspensions of nucleopolyhedrosis virus of the Douglas-fir tussock moth is presented along with the method for computing dosage rates, techniques for handling and storage of the suspensions, and the sampling procedure used to determine pre- and posttreatment viral infectivity.
Control - 6

119. Jahn, E., and K. Kotschy. 1973. Zum Auftreten des Schlehenspinners, _Orygia antiqua_ L. (Lepidoptra: Lymantriidae) bei Schwaz in Tirol (Osterreich). [Observations on the outbreak of _Orgyia antiqua_ L. (Lepidoptera: Lymantriidae) near Schwaz, Tyrol (Austria).] Ber. Naturwiss. Med. Ver. Innsb. 60:225-231.

A description is given of a mass outbreak of _Orgyia antiqua_ L., which occurred on an avalanche slope at altitudes of 1 400-1 600 m above sea level near Schwaz, in Tyrol. The larvae defoliated _Vaccinium vitis ideae_, _V. myrtillus_, _Rhododendron ferrugineum_, and _Larix eropaea_. They also partially infested cultivated spruces (_Picea excelsa_). The duration of larval development was 3-4 months. Snowfall may be responsible for latency during larval stages. The last-instar larvae were killed by a nuclear polyhedrosis virus, which collapsed the population. The 3rd-instar and older larvae proved to be resistant to insecticides applied as fogs (gama HCH) and liquid solutions (gama HCH and phosphoric acid-metasystox).
Related Material - 3

120. Johnsey, R. 1965. The Douglas-fir tussock moth in eastern Washington, 1964. Resour. Manage. Rep. 3, 11 p. April 1965. Wash. Dep. Nat. Resour.

"An aerial survey conducted in the summer of 1963 detected 40-50 farm woodlots in eastern Washington on which fir trees (primarily Douglas-fir) were being defoliated by the Douglas-fir tussock moth." Another survey conducted in the early summer of 1964 showed 72 infestation centers affecting 17,700 acres. Samples of egg masses were taken to

determine the expected population. Virus was present in all larval samples analyzed. Most of the tussock moth populations subsequently collapsed from virus infection. The new/old egg mass ratio was 1:1 or greater on 2,420 acres, and the populations were expected to increase.
Outbreaks - 2

121. Johnson, D. W., and J. S. Hadfield. 1975. Defect in Douglas-fir and grand fir top-killed by the Douglas-fir tussock moth. USDA For. Serv. R-6, Div. State and Priv. For., Portland, Oreg. 10 p. Unpubl.

"Examination in 1974 of felled Douglas-fir and grand firs top-killed by the Douglas-fir tussock moth during the 1963-1965 Burns, Oregon, outbreak showed grand fir had more visible defect than Douglas-fir. Decay was minimal in both species." Woodstaining fungi and bacteria were the most prevalent organisms isolated.
Host Relationships - 2, 3; Outbreaks - 5

122. Johnson, P. C. 1948. Natural decline of tussock moth infestations in the Inland Empire. (Abstr.) Northwest Sci. 22(1):16.

Outbreaks of the tussock moth were detected in 1947, on 10,000 acres near Colville, Washington, and on 20,000 acres near Orofino, Idaho. The incidence of parasitism had become so great by the final instar, that satisfactory natural control of the larvae was assured. Polyhedral virus disease, combined with parasites, effectively curtailed further development.
Outbreaks - 2

123. Johnson, P. C., and D. A. Ross. 1967. Douglas-fir tussock moth, Hemerocampa (Orgyia) pseudotsugata McDunnough. In Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico. Dep. For. Rural Dev., p. 105-107. Ottawa, Can.

This report summarizes the damage, hosts, life history, and control measures used against the Douglas-fir tussock moth.
General Background

124. Johnson, P. C., and D. A. Ross. 1973. La chenille a houppes du sapin de Douglas Hemerocampa (Orgyia) pseudotsugata McDunnough; Douglas-fir tussock moth. Publ. Dep. Environ. Can. For. Serv. 118F:110-112.
Article unavailable.

125. Keen, F. P. 1929. Tussock moth menace. Timberman. 30:108.

A popular account of the Douglas-fir tussock moth which includes: its first appearance as a pest in Vernon, B.C., in 1920; the areas under attack in the U.S.; a description and life cycle of the insect; the possibility of control and the need for further study of all aspects of the Douglas-fir tussock moth problem.
General Background

126. Keen, F. P. 1952. Insect enemies of western forests. U.S. Dep. Agric. Misc. Publ. 273 (Rev.), p. 90-93.

The history of outbreaks, the life cycle and description of stages, the feeding habits, the parasites and predators, and the alternatives of chemical control of the Douglas-fir tussock moth are presented.
General Background; Biology - 1, 3; Control - 1

127. Kelley, S. A., and W. J. Rompa. 1973. Public opinions about controlling the 1973 Douglas-fir tussock moth outbreak. USDA For. Serv. Pac. Northwest Reg., Div. Timber Manage., Portland, Oreg. 27 p. Unpubl.

An analysis is presented of public opinion concerning the USDA Forest Service environmental statement for the Douglas-fir tussock moth pest-management plan for controlling the Oregon-Washington outbreak of 1972-1973. The Codinvolve System for analyzing public input, devised by

Clark, Hendee, and Stanky of the Forest Service, was used to classify public response to methods of control preferred, and the reasons for the choice indicated. Responses were classified according to type of input (letter, petition, form letter, and so on), locality of respondent (rural or urban, infested or uninfested area), and the basis of interest of the respondent (such as sportsman, resource industry user).

Control alternatives examined were: DDT; biological chemicals other than DDT; harvest of damaged timber; or nonintervention. The use of DDT was supported by the majority of the respondents in both the infested and uninfested areas, primarily to prevent economic damage to the timber industry and the loss of watershed and scenic values of the area.

Appendices include tables on form of response, classification of respondent, and control preferences of concerned organizations in the area.
Control - 4

128. Ketcham, D. E., and K. R. Shea. 1977. USDA combined forest pest reasearch and development program. J. For. 75(7):404-407.

"Late in 1974 the U.S. Department of Agriculture activated the Combined Forest Pest Research and Development Program to provide technology for minimizing intolerable losses for the southern pine beetle, _Dendroctonus frontalis_ (Zimm.), Douglas-fir tussock moth, _Orgyia pseudotsugata_ (McD.), and gypsy moth, _Porthetria dispar_ (L.). Participating are departmental agencies, State agricultural experiment stations and forestry organizations, universities, and industry. This is the first time an interagency research program has been administered directly from the office of the Secretary of Agriculture. Significant progress has been made during the first three years." The organization and administration of the program are detailed.
Related Material - 2

129. Klock, G. O., and C. Huang. 1977. Some early effects of conifer defoliation on microclimate. (Abstr.) Agron. Abstr., p. 181. Am. Soc. Agron., Madison, Wis.

"A reduction in canopy as a result of insect defoliation was simulated on two 0.4-ha experimental plots in a mixed Abies grandis-Pseudotsuga menziesii stand near Lake Wenatchee, Washington. The plots were defoliated with an aerial application of Paraquat® in July 1976. Loss of needles and understory foliage from the treatment stand caused an immediate reduction in use of soil water by the plants as evidenced by the lower rate of soil water depletion when compared with a control stand during the late summer. Maximum daytime air temperatures at the 10- and 100-cm heights increased immediately after defoliation while soil surface temperatures decreased. In the following spring both daytime air and soil surface temperatures were warmer in the defoliated stand while nighttime minimum air temperatures were frequently lower. Changes in air and soil temperatures are attributed to solar energy redistribution within the forest stand and modification of the forest floor albedo and thermal constants by needle fall."
Outbreaks - 5

130. Klock, G. O., and T. L. Jones. 1976. Physical disturbance of soil by salvage logging in the Oregon Blue Mountains. (Abstr.), Annual Mtg. Northwest Scientific Assn., Chaney, Wash. p. 27. Northwest Sci.

"A survey of soil disturbance was made during 1975 on five major areas that appeared to be representative of recent salvage logging of Douglas-fir tussock moth-infested areas in the Oregon Blue Mountains. Except for isolated occurrences, these operations have not had a severe detrimental physical impact on the soil resource. Slight soil disturbance from tractors (disturbance of mineral soil less than 2-3 cm deep) averaged about 17% of the logged areas, with a range of 10-23%. Severe soil disturbance averaged about 25% (range 19-29%), leaving about 58% undisturbed. This level of disturbance is similar to that by tractor logging of green timber in this region. Research supported by Douglas-Fir Tussock Moth Program."

131. Knox, D. A. 1970. Tests of certain insect viruses on colonies of honey bees. J. Invertebr. Pathol. 16(1):152.

This is an extension of the research reported by Cantwell et al., 1966 (J. Invertebr. Pathol. 8: 228-233) concerning the effect of nine different insect viruses on honey bee colonies. Included in the tests is the nuclear polyhedrosis virus of the Douglas-fir tussock moth. No differences were observed between treated colonies and untreated controls. Test of a pathogen's impact on beneficial insects are required before potential candidates for biocontrol can be used in large-scale field experiments.

Control - 6

132. Kohler, S. 1977. Ground application of four insecticides on Douglas-fir tussock moth and western spruce budworm populations in Montana. Mont. Dep. Nat. Resour. Conserv., Div. For., Insect and Dis. Rep. 77-1, 9 p.

Report unavailable.

Control - 1

133. Kohler, S. 1977. Douglas-fir tussock moth detection and survey using pheromone-baited sticky traps, 1976. Mont. Dep. Nat. Resour. Conserv., Div. For., Insect and Dis. Rep. 77-2, 7 p.

Report unavailable.

Biology - 2; Outbreaks - 2, 3.

134. Krygier, J. T., L. Streeby, J. M. Witt, and J. Capizzi. 1973. The Douglas-fir tussock moth. The problem, alternatives, and impact. Oreg. State Univ. Ext. Serv. EC 821 (Rev.), 16 p.

The extension circular delineates for the public the status of the Blue Mountain tussock moth outbreak of 1972-1973 in Washington and Oregon. The life cycle of the insect, its capabilities as a pest, the extent of present defoliation, and the forecast for potential damage in 1973 are presented. The cycle of outbreaks appears to follow a 3-year pattern,

with the 3rd year (in this case, 1973) a period of natural population decline. Comparisons made between the estimated insect mortality and resultant reduction of defoliation with natural population decline or with chemical control by DDT show an estimated 12-369 million board feet of timber can be saved in 1973 with the use of DDT. Variation in number of board feet is dependent on the method used in making the estimate. Both the economic and environmental impact of the use of DDT is examined. The major environmental risk will be the reduction of certain populations of birds and fishes.

The circular is updated with the March 1973 report from the U.S. Forestry Lab at Corvallis, on the virus incidence in the overwintering egg masses. The virus level is lower than anticipated, and the figures for potential defoliation in 1973 have to be adjusted accordingly. Outbreaks - 2; Control - 4

135. Kulman, H. M. 1971. Effects of insect defoliation on growth and mortality of trees. Ann. Rev. Entomol. 16:289-324.

One hundred seventy-four studies of tree mortality and increment reduction related to measured amounts of insect and artificial defoliation are reviewed. Discussion of individual case studies is organized by defoliating insect. Included is a brief section of defoliation of white fir by the Douglas-fir tussock moth.

The need to relate measurement of defoliation, growth, and mortality to a complex of factors is examined. Flower production, respiration and photosynthetic efficiency of the foliage, tree age and species, season of the year, age, exposure, and crown location of the foliage all affect foliage growth, development, and response to defoliation.

Factors affecting selection of trees for experimental controls are outlined, as well as problems encountered in pre- and postdefoliation growth measurements. Trees escaping defoliation make poor controls if

factors affecting the defoliator population independently affect tree growth and mortality.
Outbreaks - 5

136. Lachenmeier, R. R. 1974. DDT and the tussock moth: The EPA in a crisis situation. Environ. Law (Winter):135-184.

The EPA's refusal to allow an emergency application of DDT against the Douglas-fir tussock moth in 1973 drew criticism in light of the widespread defoliation that occurred in the Blue Mountain infestation in the summer of 1973. This paper attempts to determine the background against which the decision was made and to analyze, criticize, and recommend changes in the EPA decisionmaking process. The life cycle and natural history of the moth, the status of the current outbreak in the Blue Mountains, the alternatives for control, and the history of the EPA control over the use of DDT are reviewed.

The USDA Forest Service Environmental Impact Statement is examined in depth, as are the reasons behind the EPA's refusal to allow the use of DDT for Douglas-fir tussock moth control, and the possibilities of political considerations influencing this decision. The article recommends that the EPA enter early in the investigation of surrounding situations where a potential exists for an EPA ruling, to ensure that the agency is in full possession of the facts.

An addendum examines the 1974 reversal by the EPA in granting an exemption from the ban on DDT for Douglas-fir tussock moth control.
Control - 4

137. Lavenseau, L. 1972. Quelques aspects de la biologie d'*Orgyia antiqua* L. (Lepidoptere, Lymantriidae). [Some aspects of the biology of *Orgyia antiqua* L. (Lepidoptera, Lymantriidae).] Soc. Linn. de Bord. Bull. 2(10):217-234.

Translation unavailable.
Related Material - 3

138. Lessard, E. D. 1974. Climatic, host tree, and site factors affecting the population dynamics of the Douglas-fir tussock moth, Orgyia pseudotsugata (McDunnough). M.S. thesis, Univ. Wash., Seattle. 69 p.

This study was initiated to analyze present and past infestations of the Douglas-fir tussock moth, and equate climatic conditions, as well as host tree susceptibility, to changes in tussock moth populations. Fifty-five infested sites were studied. Measurements of slope, aspect, elevation, and stand composition were taken. Radial sections were taken from 10 infested Douglas-fir for laboratory analysis. These were x-rayed and an oblique sequence was used to analyze growth patterns from 1955 to 1964. Leader growth was substantially reduced because of defoliation, and the leader increased in dominance relative to the rest of the tree. Climatic release may be an important factor in the population dynamics of the tussock moth, since each infestation was preceded by 1 or more years of below-normal precipitation. The number of years of below-normal precipitation is correlated with the number of acres infested during the outbreak. Stands on drier sites are more susceptible to tussock moth attack than stands on wetter sites. The quality of the foliage increases and host resistance decreases when the tree is under water stress in drought conditions. These factors may explain the sudden release of tussock moth populations because of their favorable effect on the larvae. A generalized model is given showing the interaction of population density, precipitation, and host foliage quantity and quality, as well as host susceptibility.
Host Relationships - 3; Outbreak - 4

139. Linn, J. D., and A. I. Bischoff. 1966. Progress report on the evaluation of the effects on fish and wildlife of the Douglas-fir tussock moth control project in California--1965. Calif. Dep. Fish and Game, Rep. 3, 13 p. Unpubl.

Approximately 58,000 acres of forest land were sprayed with DDT in 1965, for control of the Douglas-fir tussock moth. A surveillance program

was conducted to determine the effects of DDT on nontarget fish and wildlife. The two phases to the evaluation were general observation of direct effects during the spray operation and residue studies. Residue levels were found for fish, aquatic insects, water, terrestrial insects, foliage, and birds and mammals. No evidence was found of direct mortality in birds, mammals, or fish. But heavy mortality was found in aquatic insects. Residues on forage increased from the spray, but analysis of samples taken 2 months after spraying showed a rapid decline in residue levels. A considerable increase of residue occurred in deer and chickadees.
Control - 3

140. Livingston, R. L. 1973. 1973 test of Sevin-4-oil for control of Douglas-fir tussock moth. State of Idaho, Dep. Lands, For. Pest Rep. No. 3, 5 p.

Tests of Sevin-4-oil were conducted in 1973 in northern Idaho against the Douglas-fir tussock moth in an effort to find an alternative to DDT. Aerial application of 1 lb/acre of Sevin on 60-acre plots resulted in a 65.5% corrected mortality but good foliage protection. Low mortality appeared to be the result of low spray deposit rather than low toxicity of the insecticide. Further testing is recommended.
Control - 1

141. Livingston, R. L. 1974. Possible causes for the unexpected decline of the Douglas-fir tussock moth in 1974. (Speech presented at the Nov. 1974 Meeting of the Intermt. Forest Pest Action Council, 3 p.) Unpubl.

Presented is a summary of opinions concerning the possible causes of the unexpected decline in population at the Blue Mountain Douglas-fir tussock moth outbreak. The opinions are unsupported by data and are derived from onsite observation or from speculation. Some areas sampled in June 1974 in Washington, Idaho, and Oregon had populations lower than predicted from the fall 1973 egg-mass survey. Among the suggested reasons

for the decline are: low egg viability; egg parasites; reduced larval vigor from poor egg quality; egg hatch out of synchrony with bud flush; higher virus incidence in the spring (1974); aphid epidemic produced excess honey dew, trapping larvae; larval predators; and inaccurate predictions from 1973 surveys.
Outbreaks - 4

142. Livingston, R. L., and G. Daterman. 1977. Surveying for Douglas-fir tussock moth with pheromone. Bull. Entomol. Soc. Am. 23(3):172-174.

Efforts to survey the Douglas-fir tussock moth population with female sex pheromone traps to detect incipient outbreak populations are described. A two-phase program was designed, first, to determine if pheromone traps could better define the geographic distribution of the tussock moth; and second, to develop a trapping system that would provide advance warning of population increases. Pheromone traps have detected low level population throughout most of the host type area. Population assessment, however, has been hampered by the fact that all traps captured moths regardless of population density. Lower doses of pheromone are needed to correlate numbers of tussock moths captured with numbers of larvae detected in field surveys.
Biology - 2; Outbreaks - 2, 3

143. Livingston, R. L., and S. Tunnock. 1973. Biological evaluation of existing Douglas-fir tussock moth populations in northern Idaho to determine damage potential for 1973. Idaho Dep. Public Lands, For. Pest Rep. 2, 6 p. Unpubl.

Current tussock moth egg populations were surveyed in northern Idaho to determine their potential for causing serious tree defoliation in the spring and summer of 1973. Egg masses were collected to evaluate the incidence of nucleopolyhedrosis virus in the population. Heavy populations were found in 4 of 28 plots examined, intermediate populations in 3 plots, and only cocoons were found in the remaining 4 of the 11

plots with egg masses or cocoons. Only one old egg mass was found in all of the plots. The populations were believed to be in the release phase of an outbreak and expected to cause extensive damage in 1973.
Outbreaks - 2

144. Luck, R. F., and D. L. Dahlsten. 1967. Douglas-fir tussock moth (Hemerocampa pseudotsugata) egg mass distribution on white fir in northeastern California. Can. Entomol. 99:1193-1203.

"The distribution of Douglas-fir tussock moth (Hemerocampa pseudotsugata) egg masses on white fir (Abies concolor (Gord. & Glend.) Lindl.) was studied in three areas of northern California. In each area 100 trees between 4.5 and 8.4 inches in diameter were stratified into five defoliation classes and four crown classes, giving a total of 20 classes per study area with five trees per class. Trees were divided into four crown levels and examples were taken at each of the cardinal directions at each level. Two branches comprised a sample unit in the top half of the tree (eight branches per level) and one branch was the sample unit in the bottom half of the tree (four branches per level). Egg masses were recorded per 10 ft^2 of foliage or branch area. Eighty % or more of the egg masses were found in the bottom half of the crown. This percentage in the bottom half of the crown increased on trees with heavy defoliation or with increased exposure of the crown. Of the four possible sources of variation considered in this study, crown level, defoliation class, and crown class were significant, but cardinal direction was not. A sampling method is proposed on the basis of the information gathered in this investigation."
Host Relationships - 1; Outbreaks - 3, 4

145. Ludeman, W. W., and R. L. Livingston. 1974. Reevaluation of certain 1974 Douglas-fir tussock moth control spray and spray-option areas in north Idaho. State Idaho, Dep. Lands, For. Pest Rep. No. 4, 8 p.

The results of a population survey conducted spring 1974, to reevaluate the potential defoliation on areas previously designated as targets for control projects and to examine new areas that may contain

populations that meet spray criteria, are presented. Based on egg mass densities and estimates of present defoliation, each of the areas was rated for its defoliation hazard, and spray boundaries were adjusted accordingly.
Outbreaks - 2

146. Lyon, R. L., S. J. Brown, and C. E. Richmond. 1967. Insecticides tested on new tussock moth ... defoliator found in Montana. USDA For. Serv. Res. Note PSW-161, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

"A pine tussock moth, identified as Dasychira sp. near/= grisefacta Dyar, was found for the first time in Montana in 1965. Larvae were reared on ponderosa pine foliage in the laboratory. Six insecticides were tested by topical application on fourth-instar larvae. Contact toxicity at LD_{90}, in descending order, was as follows: pyrethrins, Zectran, malathion, DDT, SD-8530, and carbaryl."
Related Material - 3

147. Lyon, R. L., and H. W. Flake, Jr. 1966. Rearing Douglas-fir tussock moth larvae on synthetic media. J. Econ. Entomol. 59(3):696-698.

"A procedure was developed for rearing larvae of Douglas-fir tussock moth, Hemerocampa pseudotsugata McDunnough, in large numbers on a synthetic medium for use in laboratory testing of insecticides. The insects were reared from the egg stage generally to the 4th to 7th instar, depending on testing needs. The larvae appeared normal in every way, reaching a weight of about 300 mg before pupation. An initial high loss from nuclear-polyhedrosis virus in the 3rd instar was avoided by soaking the eggs with a 10%-formaldehyde solution. Mortality during the larval stage on media was about 10%. Three thousand larvae were reared per week at a cost (excluding overhead) of about $15.00. At least 25,000 larvae could be reared weekly by one person working full time."
Biology - 6

148. Lyon, R. L., H. W. Flake, Jr., and L. Ball. 1970. Laboratory tests of 55 insecticides on Douglas-fir tussock moth larvae. J. Econ. Entomol. 63(2):513-518.

"Fifty-five insecticides were tested for their toxicity to larvae of the Douglas-fir tussock moth, Hemerocampa pseudotsugata McDunnough. The 10 most active insecticides in descending order of average toxicity at LD_{90} were: pyrethrins, Dursban® (0,0 diethyl 0-3,5,6-trichloro-2-pyridyl phosphorothioate), Zectran® (4 dimethylamino-3,5-xylyl methylcarbamate), dichlorvas, GC-6506 (dimethyl p-(methythio) phenyl phosphate), aminocarb, tetramethrin, allethrin, Bayer 37298 (0-ethyl 0-2,4,5-trichlorophenyl ethylphosphonothiode), and DDT. Four of the 10 insecticides--pyrethrins, Dursban, Zectran, and DDT, have been field tested recently with varying results. Several insecticides were examined in the laboratory in more detail in different formulations for such characteristics as rate of toxic action and residual activity."
Control - 1

149. McComb, D. 1965. Entomological evaluation of the Douglas-fir tussock moth in eastern Oregon. USDA For. Serv. Pac. Northwest Reg. 6, Portland, Oreg., 12 p. Unpubl.

"Defoliation by the Douglas-fir tussock moth was heavy on 32,000 acres of Douglas-fir and true firs on the Malheur National Forest during 1964. Feeding was light to moderate on an additional 10,000-15,000 acres, Malheur and Ochoco National Forests. Larval populations were high during September, and larval mortality from virus was low except in the Gold Hill area. Results of a new-to-old egg ratio survey made during October indicated a large increase in defoliation and moth populations would occur during 1965 in all areas except Gold Hill where the population was expected to remain static."
Outbreaks - 2

150. McComb, D. 1966. Dursban and Zectran pilot control study for Douglas-fir tussock moth. USDA For. Serv. Pac. Northwest Reg. 6, Portland, Oreg., 6 p. Unpubl.

Dursban and Zectran insecticides were applied by helicopter at the rate of 1/4 lb/gal cycle oil per acre to a mixed stand of ponderosa pine and Douglas-fir in the Malheur National Forest, in 1965. Measurements were taken of spray coverage and larval mortality. Larval mortality was poor. Occurrence of a polyhedrosis virus between the 3rd and 10th day postspray, prevented attributing larval mortality to insecticides. One month after spray application, field surveys encountered large numbers of larvae and some defoliation.
Control - 1

151. McComb, D. 1973. Biological evaluation of Douglas-fir tussock moth -- Oregon and Washington 1972-1973. USDA For. Serv. Div. Timber Manage. Reg. 6, Portland, Oreg., 32 p. Unpubl.

Entomological evaluation surveys were undertaken during the fall of 1972 in the known tussock moth activity centers and in adjacent host-tree areas in Oregon and Washington. The primary objectives of the survey were to locate and delineate areas of tussock moth activity, determine the degree of damage, measure the density and trend of moth population in each area, and collect egg masses for a survey of virus disease incidence. The evaluation procedure combined aerial and ground-detection surveys and sampling of egg masses. During the ground surveys, determinations were made of egg-mass densities, new-to-old egg-mass ratios, egg-mass size, and the presence of predators and parasites.

The population trends and the need for control are discussed for each outbreak area. Upon determination of the amount and distribution of virus from the incidence surveys, a reevaluation was undertaken in each unit where control had originally been recommended for 1973.

The report includes a list of the host trees, a description of tussock moth damage, and a history of the current outbreak.
Outbreaks - 2

152. McDunnough, J. C. 1921. New British Columbia tussock moth, *Hemerocampa pseudotsugata* McD. Can. Entomol. 53(3):53-56.

The taxonomic description of the Douglas-fir tussock moth is presented, including a description of the egg stage, the five larval stages, and the adult male and female. Description was based on specimens reared from egg masses collected on Douglas-fir by W. B. Anderson (the original discoverer of the species) in Chase, B.C., spring 1920. The species had been identified by E. H. Blackmore of the B.C. Provincial Museum as *H. vetusta gulosa*. Based on differences in larval coloration and host plant preference, however, the moths collected by Anderson can be distinguished from both *H. vetusta* and *H. gulosa*, and therefore recognized as a new species.
Taxonomy

153. McDunnough, J. C. 1938. Check list of the Lepidoptera of Canada and the United States of America. Part I. Macrolepidoptera. Mem. South. Calif. Acad. Sci. 1:1-272.

A complete list of the known species of Lepidoptera in Canada and the United States is presented. *Hemerocampa pseudotsugata* McDunnough is included.
Taxonomy

154. McGregor, M. D., S. Tunnock, J. E. Dewey, and W. M. Ciesla. 1974. Pilot control project of nucleopolyhedrosis virus and *Bacillus thuringiensis* to control Douglas-fir tussock moth populations in Idaho - 1974. USDA For. Serv. North. Reg., Insect Dis. Rep. 74-26, 11 p. Div. State Priv. For., Missoula, Mont.

"A pilot control project designed to evaluate two microbial insecticides, the bacterium *Bacillus thuringiensis* and a nucleopolyhedrosis virus, against epidemic populations of Douglas-fir tussock moth was planned for two test sites in northern Idaho in 1974." The population in the proposed study area was sampled to determine if the Douglas-fir tussock moth outbreak in Idaho met criteria for a definitive

project with virus and bacteria. These criteria are: relatively high larval densities; population in a release phase; and low levels of natural virus associated with overwintering eggs. Sample data revealed larval populations at too low a level to support a definitive test at either test site and the project was cancelled. Monitoring of the population was continued to determine the effects of natural factors on a declining tussock moth population. Field-collected larvae were laboratory reared to determine mortality factors. Forty-nine percent emerged as adults, 36.7% died of unknown causes, 9.2% died from hymenopterous parasites, 1.8% from dipterous parasites, and 3.4% from virus. The nucleopolyhedrosis virus was not the major factor in population decline.

Several problems in the formulation of microbial insecticides are discussed.
Control - 5, 6

155. McLean, H. E. 1966. Twenty days in June . . . the cautious war. Am. For. 72(3):28-31, 49, 50.

A popular account of the DDT spray control project in the Malheur National Forest (Oregon) against an outbreak of the Douglas-fir tussock moth. The infestation was first discovered in 1963 and reached outbreak proportions by 1964. Fifty thousand pounds of DDT was aerially applied to 60,000 acres of Douglas-fir and white fir, between June 10 and July 1, 1965. Helicopters were used to apply the chemical to increase the precision of spray placement and minimize danger to cattle and ranches in the area. The spray project was under the control of the USDA Forest Service. The effects on both domestic and wild animals of possible DDT contamination were monitored. Postspray sampling revealed 98% mortality of Douglas-fir tussock moths in the treated areas.
Control - 2, 3

156. Maksymiuk, B. 1975. Pattern of use and safety aspects in application of insect viruses in agriculture and forestry. In Baculoviruses for insect pest control: Safety considerations, p. 123-127.

M. D. Summers, R. Engler, L. A. Falcon, and P. V. Vail, eds. Am. Soc. Microbiol.

A general discussion is presented of the safety aspects of virus formulation and field application against arthropods. Discussed are: application strategies, types of formulations and equipment, amounts of virus used, and comparisons of patterns of field use between agriculture and forest control projects. The discussion of safety aspects of application covers formulations and storage, equipment sanitation, and application drift hazards. Problems of virus preparation for specific insects such as the Douglas-fir tussock moth are mentioned.
Control - 6, 9

157. Maksymiuk, B., P. A. Boving, R. D. Orchard, and R. G. Winterfeld. 1968. Biological evaluation of helicopter spray equipment for applying polyhedrosis virus to control the Douglas-fir tussock moth. USDA For. Serv. and Agric. Res. Serv. Prog. Rep., 38 p. Pac. Northwest For. and Range Exp. Stn. and Agric. Eng. Res. Div., Corvallis, Oreg. Unpubl.

A series of helicopter spray tests were conducted near Corvallis, Oregon, as part of an effort to develop an operational procedure for control of the Douglas-fir tussock moth with polyhedrosis virus. The tests were designed to determine the effects on larval mortality of various application rates and spray atomizations.

"Two spray systems were tested. The ultralow-volume (ULV) spray system was calibrated to produce a spray atomization of 106 um mass median diameter (mmd) and an application rate of 0.2 gal per acre (gpa). The low-volume (LV) spray system was calibrated to produce spray atomization of 355 um mmd and application rates of 1.0 and 2.0 gpa. Mortalities were recorded until pupation. Distribution of spray deposit across the spray swath was determined."

The tests revealed that the ULV spray system can reduce application rates tenfold without decreasing insect mortality. Only one-half the

amount of virus was used for the application rate of 0.2 gpa as compared to either 2.0 and 1.0 gpa. "ULV application showed the most potential for field use considering biological effectiveness, spray distribution, plant coverage, simplicity of equipment, low weight of spray load, . . . and reduction in cost."
Control - 9

158. Maksymiuk, B., and J. Neisess. 1975. Physical properties of Bacillus thuringiensis spray formulations. J. Econ. Entomol. 68(3):407-410.

The effectiveness of water-base suspensions of Bacillus thuringiensis Berliner is increased by the addition of surfactants such as wetting agents, thickening agents, antievaporants, stickers, and protectants. Twelve commercially prepared, experimental B.t. spray formulations were tested and their physical properties evaluated. Emphasis was placed on selecting the most stable formulations for aerial application against forest defoliating insects.

"Four Thuricide®-HPC and four Dipel formulations were stable, while four Dipel formulations readily separated into layers during short storage. Maywood, whey, and corn oil surfactants increased the viscosity, which resulted in more stable formulations. Maywood surfactant also increased spread of formulations on foliage.

"Cargill's insecticide base (molasses) adjuvant resulted in the higher acidity of spray formulations as compared to polyethylene glycol. The various additives did not significantly improve sticking or retard evaporation of spray formulations. All formulations flowed through experimental spray equipment satisfactorily, were adequately atomized and produced consistent droplet size spectra." Little difference occurred in physical properties between Dipel and Thuricide formulations. The main criterion that would readily distinguish between formulations was the uniformity of suspensions of B. thuringiensis.
Control - 5, 8

159. Maksymiuk, B., and R. D. Orchard. 1974. Techniques for evaluating *Bacillus thuringiensis* and spray equipment for aerial application against forest defoliating insects. USDA For. Serv. Res. Pap. PNW-183, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The most promising Dipel and Thuricide forestry spray formulations and spray equipment were studied to improve aerial application techniques and the effectiveness of *Bacillus thuringiensis* against forest insects."

The spray formulations and spray equipment produced satisfactory drop-size spectra and spray-deposit patterns. It was found that selected applications of *B.t.* demonstrated high control potential for the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McD.), and the western spruce budworm, *Christoneura occidentalis* Freeman. The mean corrected larval mortality of the Douglas-fir tussock moth was 88% for the 100-ft and 78% for the 200-ft spray swath widths using Dipel. For the Thuricide treatment, the mean corrected larval mortality of the Douglas-fir tussock moth was 94% for the 100-ft and 87% for the 200-ft swath widths; the mean corrected larval mortality of the western spruce budworm was 100% for the 100-ft and 98% for the 200-ft swath widths. Higher deposits of *B.t.* almost completely prevented insect defoliation to test trees.
Control - 5, 8

160. Maksymiuk, B., R. D. Orchard, R. A. Waite, and J. Neisess. 1972. Aerial application of polyhedrosis virus against the Douglas-fir tussock moth: Equipment, formulation, meteorological monitoring, spray deposit and drift assessment. Part II. *In* Results of field experiments for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus and associated studies. USDA For. Serv. Prog. Rep., 22 p. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. Unpubl.

"This report summarizes the results of the preliminary spray tests conducted at the airport, Corvallis, Oregon, and the field test carried

Douglas-fir tussock moth." The airport tests corrected spray equipment deficiencies, and determined spray atomization, swath width, and spray deposit patterns.

The field test in California, showed a "wide variation in the amount of spray deposit both within and among individual trees. Quantitative spray-deposit assessment data showed that the foliage samples contained almost twice the amount of deposit on the Iron Mountain plot as compared to the Plummer Ridge plot. This difference is highly significant. It can be explained by the difference in precision of the spray application mainly due to swath markings and general location of plot. The amount of spray drift was highly significant in all control plots.

Due to insufficient larval mortality, no attempt was made to correlate it with the quantity of spray deposit."
Control - 9

161. Manis, H. C., and W. E. Shull. 1946. Tussock moth control. Univ. Idaho Coll. Agric. Mimeogr. Leafl. No. 95, 1 p. Agric. Exp. Stn. and Ext. Div., Moscow.

Report unavailable.
Control - 1

162. Markin, G. P., and H. Wilcox III. 1977. Douglas-fir tussock moth ground spray tests, 1974. Insectic. and Acaricide Tests 2:113-114.

Ground tests of 15 insecticides, each at 3 different rates, were conducted in the Wallowa-Whitman National Forest, from June 21 to July 10, 1974, to discover a replacement for DDT for control of the Douglas-fir tussock moth. "Based on the results of the tests (plus additional data) two materials, Orthene® 75S and TH-6040, were recommended for further field testing."
Control - 1

163. Martignoni, M. E. 1967. Separation of two types of viral inclusion bodies by isopycnic centrifugation. J. Virol. 1(3):646-647.

Nucleopolyhedrosis virus (NPV) inclusion bodies and cytoplasmic polyhedrosis virus (CPV) inclusions from larval Douglas-fir tussock moths can be separated and purified from mixed suspensions by centrifugation because of a small difference in the density of the inclusion bodies. "The inclusions are driven by centrifugal force to their isopycnic level in a sucrose density-gradient column." The centrifugations were performed in vacuo at 1°C by a BD-2 ultracentrifuge equipped with high-speed, horizontal swinging bucket rotors. "The fractionation procedure consisted of four steps."

Examination of the resulting two suspensions by dark-field microscopy showed each fraction contained only inclusions of one or the other type. Infectivity tests of the two fractions performed on tussock moth larvae showed only a trace (5.3%) of contaminating CPV in the NPV fraction and no NPV in the CPV fraction.

Isodensity levels for the virus inclusions were determined at 1.261 for NPV and 1.279 for CPV inclusion bodies.
Biology - 5; Control - 6

164. Martignoni, M. E. 1972. Production, safety evaluation, and infectivity titer assay of nucleopolyhedrosis virus preparation for field application. Part I. In Results of field experiments for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus and associated studies. USDA For. Serv. Prog. Rep., 13 p. Pac. Northwest and Range Exp. Stn., Corvallis, Oreg. Unpubl.

"A nucleopolyhedron preparation sufficient for treating 206 acres of fir forest at 10^{11} viral inclusion bodies per acre was produced by a simplified procedure. The method consisted of three principal steps: (1) propagation of the virus in Douglas-fir tussock moth larvae; (2) recovery of the inclusion bodies by homogenizing the larval tissues

and by passage of the suspension through a series of sieves; and (3) enrichment of the inclusion-body suspension by centrifugation in a sucrose solution.

"Tests to determine the safety of the viral agents for bees, fish, and mammals were completed, and gave no indication that the preparation would be unsafe for use as an insecticide. The tests were reviewed by public-health virologists. Routine production control tests confirmed that pathogenic agents (such as Shigella and Salmonella) were absent from the batch actually used in the field."

Infectivity titer of the suspension was determined by bioassay with larvae of the Douglas-fir tussock moth. Median lethal dose was 208 PIB/g larval weight. LD_{90} was estimated at 580 PIB/larvae. Pre- and postspray samples collected from the spray system nozzles showed comparable LD_{50} values when bioassayed with tussock moth larvae, demonstrating good field activity of the virus suspensions. Actual polyhedron counts of field samples were 3-13% lower than theoretically expected, possibly because of sedimentation.
Control - 6

165. Martignoni, M. E. 1972. A rapid method for the identification of nucleopolyhedron types. J. Invertebr. Pathol. 19(2):281-283.

Two nucleopolyhedron morphotypes occur in diseased Douglas-fir tussock moth larvae; single-rod virus types and bundle-rod virus types. Observation of the polyhedron dissolved in an alkali solution by dark-field microscopy gives a rapid method of discerning the ratio of the two types present in a virus suspension. Dissolved virus bundles appear as bright granules in fast Brownian movement within the outer polyhedron membrane, while the contents of the single-rod virus polyhedra appear homogeneous. Optimum area of observation of the dissolved polyhedra is found in the pH gradient formed against Tris buffer. Only freshly dissolved polyhedra can be easily identified. After a few minutes in alkaline solution, the contents of the polyhedra of both types precipitate.

A 0.02 M NaOH with 1% hydroxyethyl cellulose solution and a 0.02 M Tris buffer at pH 7.2 were used. A virus suspension was smeared on a microscope slide and let dry. One drop each of the Tris buffer and the alkaline solution were placed on a cover slip, joined together, and inverted on the slide. The slide was immediately examined.
Biology - 5; Control - 6

166. Martignoni, M. E., J. P. Breillatt, and N. G. Anderson. 1968. Mass purification of polyhedral inclusion bodies by isopycnic banding in zonal rotors. J. Invertebr. Pathol. 11(3):507-510.

Isopycnic separation of nucleopolyhedra from homogenates of larval tissue of several lepidopteran species has been performed in sucrose density-gradient columns by high-speed, horizontal swinging bucket rotors. By adaptation of the procedure for use with zonal rotors, large volumes of homogenate can be processed to produce gram amounts of pure nucleopolyhedra. The procedure could be used in decontaminating industrial batches of nucleopolyhedra if bacterial contaminants and allergens or both were undesirable.
Biology - 5; Control - 6

167. Martignoni, M. E., and P. J. Iwai. 1968. Determination of nucleopolyhedron counts and size-frequency distributions by means of a Coulter transducer. USDA For. Serv. Res. Note PNW-85, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Coulter counts of nucleopolyhedra in purified suspensions and in suspensions containing varying amounts of impurities (up to 7.9% in the size range of the inclusion bodies) gave results in good agreement with counts performed with the traditional microscopic counting chamber." With the electronic procedure, large series of preparations can be rapidly processed. The advantages and disadvantages of the automated procedure are outlined. "Polyhedron counts of suspensions containing large amounts of impurities (such as raw tissue homogenates) gave unreliable results by electronic as well as microscopic procedures. In such cases, biological assay remains the only reliable method for the determination of infectivity titers."

With the model B Coulter counter, size-frequency distributions of batches of nucleopolyhedra could be established based on large numbers of particles.
Biology - 5; Control - 6

168. Martignoni, M. E., and P. J. Iwai. 1977. A catalog of viral diseases of insects and mites. 2d ed. USDA For. Serv. Gen. Tech. Rep. PNW-40, 27 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. (1st ed., 1975.)

"This computer-based catalog lists over 640 species of insects and mites, each reported to have one or more of 21 viral diseases or disease groups, for a total of about 1,000 host-virus records." Hosts are listed both in taxonomic sequence in one list, and alphabetically by specific names in a second list.
Biology - 5

169. Martignoni, M. E., and P. J. Iwai. 1977. Peroral bioassay of technical-grade preparations of the Douglas-fir tussock moth nucleopolyhedrosis virus (Baculovirus). USDA For. Serv. Res. Pap. PNW-222, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The potency of industrial preparations of viruses for control of injurious insects can be estimated reliably only by means of biological assay. We describe a simple, yet sensitive peroral bioassay procedure for technical-grade preparations of nucleopolyhedrosis virus. This procedure has been accepted by the Forest Service and the U.S. Environmental Protection Agency as the standard method for assaying industrial virus preparations for control of the Douglas-fir tussock moth."
Biology - 5; Control - 6

170. Martignoni, M. E., and P. J. Iwai. 1977. Thermal inactivation characteristics of two strains of nucleopolyhedrosis virus

(Baculovirus subgroup A) pathogenic for Orgyia pseudotsugata. J. Invertebr. Pathol. 30(2):255-262.

"Two nucleopolyhedrosis viruses of the Douglas-fir tussock moth, Orgyia pseudotsugata, one with a single nucleocapsid per envelope (SV) and one with multiple nucleocapsids per envelope (BV) are inactivated by a first-order reaction at 55° and 60°C. BV is the more thermostable of the two viruses: at both test temperatures, it has a lower inactivation rate than SV. BV is also the more virulent of the two viruses, with respect to acute course of the disease and severity of the histological lesions. The greater thermostability of BV and the acute course of the disease caused by this pathogen support the choice of BV as the virus most suitable for industrial production and field use."
Biology - 5

171. Martignoni, M. E., P. J. Iwai, and J. P. Breillatt. 1971. Heterogeneous buoyant density in batches of viral nucleopolyhedra. J. Invertebr. Pathol. 18(2):219-226.

"Nucleopolyhedron preparations of the bundle virus strain, obtained from large volumes of tissue homogenates of Hemerocampa pseudotsugata larvae, contain populations of inclusion bodies which differ with regard to their buoyant density in isopycnic sucrose gradients. The heavier polyhedra contain higher numbers of virus rods per polyhedron as well as higher numbers of rods per virus bundle. Polyhedra of the single-rod virus strain occlude larger virus rods and band at higher density than bundle virus polyhedra with similar numbers of virus rods. This fact favors the hypothesis that the single-rod and the bundle virus strains are distinct entities. This study includes a determination of the sedimentation constants of two polyhedron fractions, a mathematical simulation of the sedimentation behavior of nucleopolyhedra in isopycnic sucrose gradients, and an empirical analysis of the sedimentation of a polyhedron fraction. These data are intended to provide further criteria for improving the purification of polyhedral inclusion bodies in Anderson's zonal rotors."
Biology - 5; Control - 6

172. Martignoni, M. E., P. J. Iwai, K. M. Hughes, and R. B. Addison. 1969. A cytoplasmic polyhedrosis of Hemerocampa pseudotsugata. J. Invertebr. Pathol. 13(1):15-18.

"Histochemical and histological studies of midguts of larvae of the Douglas-fir tussock moth, Hemerocampa pseudotsugata, infected with cytoplasmic polyhedrosis virus showed that the viral inclusion bodies formed in apicobasally oriented rows in goblet and columnar cells of the epithelium. Electron micrographs of ultrathin sections of infected cells in the late stages of the disease revealed that the cytoplasmic polyhedra were surrounded by high numbers of virus particles, adjacent to the surface of the inclusion bodies. Biological assay gave an LD_{50} estimate of 104 polyhedra/g larval weight. In our samples, the mean volume of the inclusion bodies was 7.7 μ^3 and the mean diameter of the virus particles was 56 mμ."
Biology - 5

173. Martignoni, M. E., P. J. Iwai, and L. J. Wickerham. 1969. A candidiasis in larvae of the Douglas-fir tussock moth, Hemerocampa pseudotsugata. J. Invertebr. Pathol. 14(1):108-110.

A yeast isolated from the alimentary tract of a laboratory-reared larva of the Douglas-fir tussock moth was classified as Candida zeylanoides (Castellani) Langeron and Guerra (designated strain Y-7043) on the basis of cell and colony morphology, carbon assimilation reactions, and sugar fermentation.

Infectivity tests of yeast cells from 2-day-old surface colonies on 4th-instar tussock moth larvae resulted in a slight inhibition of growth with low inoculative doses and a high mortality with high doses. No pathognomonic symptoms of the candidiasis appeared in the tussock moth larvae. The frequency of yeast cells in the fresh feces served as a diagnostic test. The yeast multiplies abundantly in the slightly acidic hindgut of the larvae.

"C. zeylanoides, strain Y-7043, appears to be a conditioned enteropathogenic microorganism for larvae of H. pseudotsugata." Secondary etiological factors may have influenced both its appearance in the laboratory and the results of the infectivity tests. Lowered resistance in the host is often required for successful colonization by certain yeasts. Both the larvae from which the yeast strain was isolated and the larvae used for the tests were reared on an artificial diet. Because artificial diets may lower resistance in laboratory-reared insects, the yeast may cause disease in the laboratory where it would not do so in the field.
Biology - 4

174. Martignoni, M. E., and R. L. Langston. 1960. Supplement to an annotated list and bibliography of insects reported to have virus diseases. Hilgardia 30(1):1-39.

This supplement to Hughes's (1957) "Annotated List and Bibliography" adds 473 references to the 259 of the original list. Almost all the papers have been seen in the original or in photostatic copy. Translators were consulted when needed. Papers in Japanese and Russian included in the supplement were available in translation or contained a complete translated summary. They form only a small portion of the papers in those two languages available on this subject.

An attempt was made to distinguish between nuclear polyhedrosis and cytoplasmic polyhedrosis whenever the information was available. Both a host list and a list of general references is included.
Biology - 5

175. Mason, R. R. 1967. Evaluation of a Douglas-fir tussock moth population near Aztec Peak, Arizona. USDA For. Serv. Prog. Rep., 10 p. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. Unpubl.

"An evaluation was made in 1967 of an incipient outbreak of the Douglas-fir tussock moth in the Sierra Ancha Mountains of Arizona.

Purposes of the evaluation were to assess the suitability of the area for a field test of a virus introduced to control the tussock moth." The secondary objectives were to test methods of sampling eggs and larvae, especially at low population levels and to study dynamics of a natural tussock moth population through one or more generations. The populations were sampled three times during the season; twice during the larval stage and once in the egg stage. Major findings of the study follow.

Larval populations in 1967 were variable but low at all 10 permanent sample points. Fall egg populations indicated a substantial increase in population might occur in 1968. Significant defoliation could be expected in one 40-acre area, where heavy egg populations indicated potential outbreak status. The rest of the area under observation would still have relatively low populations. The highest populations were at a level suitable for virus test, but occurred over too small an area for adequate experimental design. Continued study is recommended to provide data on population trends and information on the mechanisms of population fluctuation.
Outbreaks - 4

176. Mason, R. R. 1969. Sequential sampling of Douglas-fir tussock moth populations. USDA For. Serv. Res. Note PNW-102, 11 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Sequential plans have been constructed for sampling eggs and larvae of the Douglas-fir tussock moth. The plans are a standardized method for making quick ground surveys of incipient outbreaks. They are designed to be applied independently at selected points in a suspected infestation for distinguishing currently innocuous populations from those having outbreak potential. The sequential schemes are recommended primarily for sampling tussock moth larvae in the early instars."

The basic sample unit is a collection of branches taken representatively from a tree. Population size is the density of young larvae or eggs per 1,000 in^2 of branch area (square inches occupied by

foliage on a branch). A two-class sequential scheme set class limits of 10 or less 1st-instar larvae or eggs per 1,000 in^2 of branch area for light populations; and 20 or more 1st-instar larvae or eggs for heavy populations with high outbreak potential. Sample points consist of about 1-acre areas from which trees are randomly selected and sampled.

Data used in developing the sequential sampling methods in this paper were taken from tussock moth infestation on white fir and may not be representative of infestations in other host species.
Host Relationships - 1; Outbreaks - 3

177. Mason, R. R. 1970. Development of sampling methods for the Douglas-fir tussock moth, Hemerocampa pseudotsugata (Lepidoptera: Lymantriidae). Can. Entomol. 102(7):836-845.

"Methods were developed to standardize sampling of the Douglas-fir tussock moth. Population density was estimated in terms of the number of eggs or larvae per 1,000 in^2 of branch area of Abies concolor (Gord. and Glend.) Lindl. The density of eggs and larvae varied significantly in different parts of the tree crown. In an outbreak, egg masses were concentrated on inside branches near the bottom of the crown, but in light populations they were most common on outside branches in the top of the crown. Larvae were found over the entire tree, but they were especially concentrated on foliage in the top. Mean density of larvae in the middle crown was representative of the whole tree. Egg density is estimated from whole branches sampled representatively from three crown levels; however, density of larvae is estimated accurately from 17-in twig samples taken from just the middle crown. Because eggs are clumped in masses and larvae are dispersed over the foliage, larval density can be estimated with much less sampling than can egg density for the same precision."
Host Relationships - 1; Outbreaks - 3

178. Mason, R. R. 1972. Analysis of population density after virus treatment of a natural outbreak of the Douglas-fir tussock moth. Part III.

In Results of field experiments for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus and associated studies. USDA For. Serv. Prog. Rep., 12 p. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. Unpubl.

"Estimates of tussock moth population density were made five times during the larval cycle on virus-treated and untreated test plots. Purposes of the measurements were to compare population trends and survival on the treated with the untreated plots. Life tables were also constructed using the mortality data provided from laboratory rearings. Major findings of the study are as follows: Sampling methods were adequate for evaluating the test and consistently gave a realistic appraisal of the natural population. Most standard errors were within 15% of the mean. Population trends and survival over the course of larval development were similar on both virus-treated and untreated plots. Larval density dropped sharply early in the cycle and then declined gradually to pupation. Overall larval survival was about 18%.

"In a life table analysis, virus disease accounted for 6% of the mortality on treated plots and 2.5% of the mortality on untreated plots. The largest proportion of mortality (over 80%) on all plots was not identified."

Control - 6

179. Mason, R. R., ed. 1973. Newsletter. Douglas-fir Tussock Moth Research Committee. Corvallis, Oreg. No. 1-Mimeogr.

The Douglas-fir Tussock Moth Research Committee is an informal group of entomologists, organized in 1972 to coordinate tussock moth field research in 1973. Its major function is to circulate information through these periodic newsletters which briefly describe the current research activity and report early research results.

Related Material - 2

180. Mason, R. R. 1974. Population change in an outbreak of the Douglas-fir tussock moth, Orgyia pseudotsugata (Lepidoptera: Lymantriidae), in central Arizona. Can. Entomol. 106(11):1171-1174.

The population growth and natural decline of an isolated outbreak of the Douglas-fir tussock moth is described. The investigation was conducted from 1967 to 1971 on an infestation near Aztec Peak, Arizona.

Data from this study support the general observation that outbreaks pass through a 3-year cycle of population release, peak, and decline. "Growth rate of populations was independent of larval density in the 1st year, but thereafter became a reciprocal function of density, terminated by complete population collapse at the end of the 3rd year. Through correlation analyses, it was found that density of small larvae accounted for a large proportion of the change in population density between years. . . . The close relation between larval density in any two successive years indicates that the outbreak developed from a population that was resident in the area for at least two years. This suggests that, at low densities, dispersal of small larvae is primarily in local redistribution in the stand and does not result in significant long-distance spread of the population the same year. Variation in densities between localities must reflect differences in natural environmental factors which influence rates of increase during release and ultimate population levels reached in the peak phase."
Outbreaks - 4

181. Mason, R. R. 1976. Life tables for a declining population of the Douglas-fir tussock moth in northeastern Oregon. Ann. Entomol. Soc. Am. 69(5):948-958.

"Changes in population density and their causes were quantified on 22 sample plots representing 4 different defoliation intensities in a Douglas-fir tussock moth outbreak. Density of larvae was extraordinarily high at the beginning of feeding in June 1973. Thereafter, populations either declined sharply or completely collapsed on all of the plots

studied. Measurable larval populations of the subsequent generation were found on only six plots in June 1974, and these had virtually disappeared by midsummer. Rate of decline was variable under different conditions but appeared to be predictable from the level of past defoliation. In general, the decline rate was faster on heavily or moderately defoliated plots than on lightly or previously undefoliated plots. Population collapse was the result of a multitude of natural factors operating in compensating ways against the high-density outbreak. It was characterized by an increase in the effect of numerous mortality factors including virus disease, insect parasites, predators, starvation, and larval dispersion, as well as changes in population quality and structure resulting in lower fecundity, and egg quality and a change in sex ratio. The largest proportion of mortality occurred early in the larval cycle and was probably because of losses from natural dispersion and predation; however, other factors may have had an equal or greater effect on ultimate collapse of the population although they accounted for less total mortality."
Outbreaks - 4

182. Mason, R. R. 1977. Advances in understanding population dynamics of the Douglas-fir tussock moth. Bull. Entomol. Soc. Am. 23(3):168-171.

A brief review is presented of the methods of Douglas-fir tussock moth population survey and the results of the studies of population dynamics. Both the conventional method for sampling insect populations and a new technique for estimating low population densities are described. Population surveys have revealed: that the Douglas-fir tussock moth is present in low numbers in most of its natural host type; that outbreaks occur with some periodicity, although not always in the same stand; and that populations are regulated at low levels by a complex of mortality factors including predation by birds and parasitism and predation by other arthropods. Although factors leading to population release have not yet been elucidated, much of the information on population dynamics has been incorporated into models.
Outbreaks - 3, 4

183. Mason, R. R. 1977. Sampling low density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower tree crown. USDA For. Serv. Res. Pap. PNW-216, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"A new method is described for rapidly estimating the larval density of low-level populations. Densities of 1.0 or fewer larvae per 1,000 in^2 (0.64 m^2) of branch area in the midcrown of host trees can be predicted from the proportion of sample units that are infested in the lower tree crown. This procedure is an improvement over the conventional midcrown sampling method because observations can be made in the more accessible lower crown without clipping and measuring branches. The technique is especially applicable to low-level populations which require the examination of large amounts of foliage to estimate larval density."
Outbreaks - 3

184. Mason, R. R., and J. W. Baxter. 1967. Studies of the biology and behavior of the Douglas-fir tussock moth, 1966. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg., 28 p. Unpubl.

"Studies were initiated in the summer of 1966 on the biology and behavior of the Douglas-fir tussock moth in a declining outbreak in northern California. An unusually late spring frost killed most of the new tip growth on white fir branches and deprived young larvae of their preferred food. The situation prompted a number of short experiments on food quality in the laboratory and larval behavior in a natural forest environment. . . .

"All larval instars fed more on new foliage than on old. Old needles were almost totally unacceptable to early instar larvae but were fed upon by late instars. When new fir foliage was not available in the field, larvae often migrated to pine, where they fed on new needles. However, in the laboratory, new fir foliage, when available, was favored over new pine foliage.

"Lack of acceptable food for early instar larvae stimulated wandering in the laboratory. . . . When larvae were fed only frost-damaged foliage which contained no new growth, a large number died, apparently of starvation. Survivors on damaged foliage were stunted and developed slower than larvae that were fed normal foliage.

"Female moths reared in the laboratory contained an average of 200 eggs per individual, but this was considerably higher than the average number of eggs per mass in the field. . . .

"Larvae tend to avoid high light intensities and temperatures by remaining on the underside of branches and needles that are exposed to the sun. Most activity and feeding by late-instar larvae occurred in the evening, night, and early morning. . . . Early instar larvae usually concentrated in the vicinity of new buds; later instars fed further back on the branch as the season progressed."
Biology - 1; Host Relationships - 1

185. Mason, R. R., and J. W. Baxter. 1970. Food preference in a natural population of the Douglas-fir tussock moth. J. Econ. Entomol. 63(4):1257-1259.

"Food selection by larvae of Hemerocampa pseudotsugata McDunnough was studied in an outbreak on white fir, Abies concolor (Gordon and Glendenning) Lindley, in northern California." Larval feeding preference in relation to age of foliage was determined by categorizing each branch into (1) new foliage, branch tip including all new growth plus 3 inches of woody twig and old foliage; and (2) old foliage, the remainder of the branch. New foliage of white fir, when it was available, was preferred over old foliage, especially by young larvae, but old needles became more acceptable as larvae matured and new foliage was depleted. Given a preference test between fir or ponderosa pine in the laboratory, larvae strongly favored new foliage of white fir. However, new foliage of pine was as attractive as old foliage of white fir. "A shortage of preferred food stimulated mobility among early instars. When larvae were fed only

frost-damaged foliage which contained no new growth, many died, apparently from starvation." Mortality of larvae on damaged fir was 74%. The highest death rates occurred in the 3rd and 4th instars.
Biology - 1; Host Relationships - 1

186. Mason, R. R., R. C. Beckwith, and H. G. Paul. 1977. Fecundity reduction during collapse of a Douglas-fir tussock moth outbreak in northeast Oregon. Environ. Entomol. 6(5):623-626.

"Fecundity of tussock moth populations varied among plots after the 1st year (1972) of conspicuous tree defoliation and declined sharply after a 2d year (1973) of defoliation. Degree of defoliation in the 1st year had no significant effect on egg production, although fewest eggs per mass were produced in the most severely defoliated areas. Severe tree defoliation in the 1st year significantly affected quality of the filial generation. Field populations that had not already collapsed naturally had a 30% drop in fecundity after the 2d yr of defoliation. The conclusion is that fecundity was influenced by many factors, food-related and otherwise, in the outbreak. Tree defoliation had its greatest effect at exceptionally high population densities when the favored current needles were destroyed early in the summer, placing surviving larvae under a food stress for much of their development."
Biology - 1, Outbreaks - 4, 5

187. Mason, R. R., and C. G. Thompson. 1971. Collapse of an outbreak of the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* (Lepidoptera: Lymantriidae). USDA For. Serv. Res. Note PNW-139, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"An outbreak population of the Douglas-fir tussock moth on white fir in northern California was studied during the summer of its collapse." Eight study points were established, three in transitional zones of less than 30% defoliation and five in the center of the heaviest defoliation (more than 30%). Mortality of larvae from parasites and disease was determined from laboratory rearings of field-collected larvae.

The survivorship curves were constructed for larvae, one from data from the heavily infested area and the second from the points in the lightly infested area. A general life table for eggs and larvae was prepared by pooling data from all study points. "The major cause of the collapse was a natural epizootic of virus disease in larval population. However, a late spring frost which destroyed much of the preferred food of the early-instar larvae may have also contributed significantly. . . . Two species of ichneumonid parasites were responsible for most of the larval parasitism recorded. . . . Density of early-instar larvae declined more sharply in heavy than in light population areas, which suggests that larval survival was partially density-dependent."
Outbreaks - 4

188. Mathers, W. G. 1949. Douglas-fir tussock moth. Can. Dep. Agric. For. Insect Invest. Bi-Mon. Prog. Rep. 5:4.

In previously recorded outbreaks of the Douglas-fir tussock moth in British Columbia, heavily infested areas seldom exceeded 1,000 acres. In the 1948 outbreak in the Kamloops Forest District, infested areas of 2,500-3,000 acres were found. Field surveys of larvae and cocoons indicated a sharp population decline with heavy larval mortality from disease and parasitism. Dipterous and hymenopterous parasites were numerous in heavily infested areas. Most commonly observed Hymenoptera were _Hyposoter_ spp. and _Pimpla pedalis_. Very few egg masses were found in the November 1948 survey. A continued Douglas-fir tussock moth outbreak in 1949 is not deemed likely.
Biology - 3; Outbreaks - 2

189. Meyer, H., and R. Lyon. 1966. Instar observations of the Douglas-fir tussock moth. 10 p. Unpubl. (On file: Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.)

Variations in number and length of larval instars in the Douglas-fir tussock moth were studied in the laboratory. Measurements were made of head-capsule width and larval length. Range of the

head-capsule widths overlapped in the 4th-6th instars, preventing the use of this character to detect instars. Little could be concluded from the measurements of larval length. The larval growth pattern was erratic. The time spent in a given instar varied, as did the number of instars (5-7). Long periods of growth in the 6th instar were observed. All larvae maturing to adults after seven instars were female, and 70% of the five-instar larvae were males.
Biology - 1

190. Migunda, J. 1970. Charops sp. (Hymenoptera: Ichneumonidae) a larval parasite of Orgyia mixta Snell. E. Afr. Agric. For. J. 36(2):231-233.

Investigations of the African tussock moth, Orgyia mixta Snell. in a Pinus radiata D. Don plantation in Kenya, revealed an abundance of larvae parasitized by the ichneumonid, Charops sp. Field-collected larvae reared in the laboratory were 100% parasitized in the 4th-6th instars, 50% parasitized in the 3rd instar, and virtually without parasites in the 1st and 2nd instars. Larvae are parasitized in the late stages of the 3rd instar, and mature parasite larvae emerge from the 5th or 6th instar of the host leaving behind the empty larval skin of the moth. Larval Charops sp. then attach to a support, spin a cocoon, and pupate. Duration of the egg-to-larval stage is about 3 weeks, and the pupal stage about 13 days. Adult longevity ranges from 3-4 days. Hyperparasitism by a chalcid Brachymeria sp. was common in the field but nonexistent in the laboratory.
Related Material - 3

191. Mills, J. 1974. Forest management: NACA discusses the tussock moth and gypsy moths and DDT. Nat. Pest Control Oper. News 34(8):18-19.

The controversy concerning the control of the Douglas-fir tussock moth by DDT is discussed. The life cycle of the moth, its method of dispersion, the effects of population outbreaks on host trees, the safety and health hazards posed both by the insect and its defoliating activity, and the estimated acreage affected and timber lost are outlined. Public opinion polls on control of the current outbreak in Idaho, Oregon, and

Washington, show strong support for the use of DDT. The reasons behind the EPA's decision to grant an emergency authorization for the use of DDT are briefly detailed. The emphasis is on problems encountered in making forest management decisions.
Control - 4

192. Morris, O. N. 1963. A nuclear polyhedrosis of Orgyia pseudotsugata: causative agent and histopathology. Can. J. Microbiol. 9(6):899-900.

This paper presents the results of a study on the causative agent and histopathology of the virus disease that affects field populations of the Douglas-fir tussock moth. The causative agent is a nuclear polyhedrosis virus with an average diameter of 1.5 μm. Early 4th-instar larvae were fed 10^8 polyhedra, and the histopathology of the disease followed in a series of larvae examined every 48 hr. The course of the infection is similar to nuclear polyhedrosis infections in other Lepidoptera. Within 4 days, the fat body cells exhibited an increase in nuclear size and coagulation of nuclear chromatin. On the 6th day, polyhedral bodies appeared in the fat body, hypodermis, and trachea. The host died on the 8th day. Breakdown of fat body, hypodermis, and tracheal matrix occurred. Blood cells and the nervous system were heavily infected.
Biology - 5

193. Morris, O. N. 1963. Pathogenicity of three commercial preparations of Bacillus thuringiensis Berliner for some forest insects. J. Insect Pathol. 5(3):361-367.

Three commercial preparations of Bacillus thuringiensis Berliner (Biotrol®, Thuricide, and Bakthane® L69) were laboratory tested against larvae of five forest insects. Because crystalline inclusions have a more immediate toxic effect than spores, a method for approximating the ratio of spores to crystals in commercially prepared B.t. is presented. Larvae used in the tests were all field-collected 3rd and 4th instars. "All three preparations demonstrated high pathogenicity for the satin moth, Stilpnotia salicis (Linnaeus), moderate pathogenicity for the

western oak looper, Lambdina fiscellaria somniara (Hulst.), and relatively low pathogenicity for the western hemlock looper, Lambdina fiscellaria lugubrosa (Hulst.), and the western tent caterpillar, Malocosoma pluviale (Dyar)." Biotrol was moderately pathogenic for Orgyia pseudotsugata, the Douglas-fir tussock moth, but Bakthane L69 and Thuricide showed low pathogenicity. "Fifty % mortality occurred in 3-4 days for S. salicis and in 6-7 days for the remainder, except for M. pluviale, in which case this figure was not reached even after 7 days."
Control - 5

194. Morris. O. N. 1963. Pathogens recovered from forest insects in British Columbia, 1947-1963. Can. Dep. For. Interim Res. Rep. 25 p. For. Entomol. and Pathol. Lab., Victoria, B.C. Unpubl.

A list of the pathogens recovered from forest insects in British Columbia between 1947 and 1963, compiled from the records accumulated by the late S. M. Sager, D. A. Fetherstonhaugh, and O. N. Morris. Identification of fungi was confirmed by the staff of the Insect Pathology Research Institute, Sault St. Marie, Ontario. About 11,000 insect specimens, representing 159 species, were examined for pathogens. Table 1 lists the pathogens, hosts, location, and year of collection. Table 2 lists the number of insects examined and the number found infected with one or more pathogens.
Related Material - 3

195. Morris, O. N. 1963. The natural and artificial control of the Douglas-fir tussock moth, Orgyia pseudotsugata (McDunnough), by a nuclear polyhedrosis virus. J. Insect. Pathol. 5(4):401-414.

"Field populations of the Douglas-fir tussock moth . . . in the interior of British Columbia, Canada, are infected with a nuclear polyhedrosis virus. Eighty-eight to 100% of the laboratory reared 3rd-instar larvae died from the virus when larvae were fed Douglas-fir foliage . . . dipped in a suspension containing 10^7 to 10^9 polyhedra/ml.

"In field studies, a high incidence of the disease was present in young larvae and this increased to 100% in samples of late-instar larvae. Although many parasites are known to attack the tussock moth, control by these agents in the present study appeared negligible, as was control by disease organisms other than the virus. A high incidence of advanced virus infection in the early instars suggested that a certain proportion may have been infected by the transovum transmission of the virus. Indications are that factors, other than density-dependent ones, were operative in this epizootic. The number of cocoons found at the end of the season was extremely low. There is good evidence to suggest that the virus is the main cause for the population collapse frequently observed in this species.

"Results of artificial dissemination of a virus suspension show that storage of virus material in the wet state for 7 years reduced the virulence of the virus for field application. Fresh virus material, sprayed as a suspension containing 107 polyhedra/ml of 1.0% Lovo, produced 90% mortality in recovered larvae."
Biology - 5; Control - 6

196. Morris, O. N. 1970. Precocious development of adult characteristics in virus infected Lepidoptera. J. Invertebr. Pathol. 16(2):173-179.

Precocious development of antennae, mouthparts, adult-type forelegs, and partial fusing of ocelli were recorded in Douglas-fir tussock moth and oak looper larvae infected by nuclear polyhedrosis virus. Larvae were laboratory reared from field-collected eggs and infected in the 4th instar. The larvae ceased feeding after the teratological alterations appeared and death occurred about a week later. "During the progressive stages of pathogenesis, the amount of aldehyde-fuchsin-stainable neurosecretory products decreased in the larval brain, but increased in the corpora allata." There may have been a direct or indirect inhibition of the corpora allata by the virus, which prevented the production and release of enough juvenile hormone for maintenance of the larval state.

The study suggests "that virus infections in insect populations may affect the hormone balance and timing of hormone activity, resulting in prothetelic conditions, cessation of feeding, and death."
Biology - 5

197. Morris, O. N. 1972. Susceptibility of some forest insects to mixtures of commercial Bacillus thuringiensis and chemical insecticides, and sensitivity of the pathogen to the insecticides. Can. Entomol. 104(9):1419-1425.

"Experiments were designed to determine the effects of low doses of some insecticides on the viability and physiological characteristics of commercial Bacillus thuringiensis (Berliner) as a prelude to studies on the susceptibility of lepidopterous forest defoliators to mixtures of bacteria and insecticides." Insecticides used were: pyrethrum, malathion, phosphamidon, Zectran, and Butacide®. "The results show that the insecticides tested had no effect on viability or physiological integrity of the bacteria."

Combinations of bacteria and insecticides at various concentrations and formulations were tested on field-collected larvae of Halisidota argentata, Malacosoma disstria, Hyphantria cunea, and Orgyia pseudotsugata. "Bacteria-insecticide combination effects varied from strongly antagonistic to strongly supplemental, depending on insecticide or Thuricide formulations and concentrations and on the relative susceptibility of the test species to either agent applied separately. . . . Among O. pseudotsugata, malathion at 10^{-5} and pyrethrum at 10^{-3} dilutions were weakly supplemental to B.t. used at 10^{-3} dilution. All other insecticide treatments appeared to be subadditive or antagonistic. In general, combination effects were more often supplemental at the higher B.t. concentration."

Treatment with B.t. generally produced a drastic reduction in feeding activity and a further reduction was evident among larvae treated with B.t. and chemical insecticide compared with controls.
Control - 1, 5

198. Morris, O. N. 1973. Dosage-mortality studies with commercial Bacillus thuringiensis sprayed in a modified Potter's tower against some forest insects. J. Invertebr. Pathol. 22(1):108-114.

"Dosage mortality tests were carried out with commercial Bacillus thuringiensis (B.t.) (Dipel) against various instars of the spruce budworm, Choristoneura fumiferana, the white-marked and Douglas-fir tussock moths, Hemerocampa leucostigma and Orgyia pseudotsugata, and the gypsy moth, Porthetria dispar. Dipel was applied as a dilute (10^{-2}) molasses suspension onto artificial diet surface in a spray tower designed to simulate aerial application. Probit analysis of the results showed that LD_{50}'s expressed both in terms of gallons deposited per acre and as spores and crystals deposited per cm^2, increased with larval age for all species. The spruce budworm was the most sensitive to the bacteria, followed in decreasing order of sensitivity by the white-marked tussock moth, Douglas-fir tussock moth, and the gypsy moth. The mean slopes for all instars of the four species were 1.6, 3.1, 2.6, and 2.2 respectively, indicating that the assay of B.t. on artificial medium was good. The relatively low slope for spruce budworm is explained by its peculiar feeding habits. Among all species tested, bacteria-treated larvae gained weight at a considerably reduced rate compared with untreated ones. Reduction in weight resulting from lowered feeding activity intensified as dosage rates increased. The implication of this in terms of mortality assessments in microbial control operations is discussed.

"It is suggested that 0.02 gal ($4x10^6$ International Units) of Dipel Molasses deposited per acre may achieve economic control of 4th-6th instar budworm and 1st-2nd instar gypsy moths. A deposit rate for 2nd-5th instar white-marked and Douglas-fir tussock moths appeared to be in the vicinity of 0.01 gal ($2x10^6$ IU) per acre."
Control - 5; Related Material - 3

199. Morris, O. N. 1975. Susceptibility of the spruce budworm, Choristoneura fumiferana, and the white-marked tussock moth, Orgyia leucostigma, to Bacillus thuringiensis: chemical insecticide combinations. J. Invertebr. Pathol. 26(2):193-198.

"*Bacillus thuringiensis* mixed with the organophosphate insecticides, fenitrothion (Sumithion®), Gardona®, and Orthene, or the synthetic pyrethroid, SBP 1382, was incorporated into synthetic diet and fed larvae of the spruce budworm, *Choristoneura fumiferana*, and the white-marked tussock moth, *Orgyia leucostigma*." All larvae were disease-free, 4th-instar reared in the laboratory. "Mortality was highest when larvae were fed combinations of low concentrations of the insecticides and low to moderate concentrations of the pathogen. The data indicated that applications of a *B.t.* dosage expected to produce about 45% mortality of the 3rd- and 4th-instar larvae of the spruce budworm combined with a dosage of fenitrothion causing about 40% mortality or a dosage of Orthene causing from 5-25% mortality should result in low budworm survival. With a *B.t.* dosage causing 20-60% mortality combined with a fenitrothion dosage causing 15-50% mortality or a sublethal dosage of Gardona, a low survival rate of young white-marked tussock moth larvae may be expected." No additive effect appeared for the *B.t.* - pyrethrum (SBP 1382) combination for either species of moth.
Related Material - 3

200. Mounts, J. 1976. 1974 Douglas-fir tussock moth control project. J. For. 74(2):82-86.

"In June and July of 1974, 427,000 acres of Douglas-fir and grand fir timberlands in Oregon, Washington, and Idaho were treated with DDT to control the Douglas-fir tussock moth. This was the largest all-helicopter forest spray project ever carried out in the United States and required cooperation by many State and Federal agencies, universities, and private landowners. Almost total insect mortality occurred immediately after treatments were applied. Defoliation ceased almost completely, and a high proportion of foliage was saved." The development of the outbreak, the planning and application of control measures, the effects on timber, and the impact on wildlife are described.
Control - 2

201. Mounts, J., D. McComb, S. W. Meso, L. F. Kline, and G. C. Trostle. 1973. Cooperative tests of chemical insecticides for control of the Douglas-fir tussock moth - 1973. USDA For. Serv. Reg. 6, Portland, Oreg. 41 p. Unpubl.

Four insecticides were tested in the Blue Mountain (Oregon-Washington) Douglas-fir tussock moth outbreak in 1973, in an attempt to find a replacement for DDT. The chemicals tested were: Zectran, at two dosage rates; Dylox, at two dosage rates; Sevin; and BEM. Application was by helicopter.

Populations were surveyed before treatment to determine density levels, areas of infestation, and virus incidence. Each chemical was tested at four independent outbreak areas, with relatively high tussock moth populations. Populations were sampled repeatedly after treatment. Assessments of spray deposit, foliage retention, and effects on nontarget insects were made. Environmental monitoring covered water quality, small mammal populations, and aquatic populations. Individual insecticide tests are covered separately in the report as are operational procedures and personnel.

"Results of the tests were highly variable and somewhat inconclusive." Larval mortality with Zectran, Dylox, and Sevin was high but the amount of foliage saved was not satisfactory. BEM gave poor results on larval mortality, possibly from too low an application rate. Control - 1

202. National Forest Products Association. 1973. The tussock moth epidemic: Why chemicals are needed to control forest pests. Natl. For. Prod. Assoc., Washington, D.C. 6 p. (Insert to Oct. 26, 1976, Newsletter.)

The background is given of a tussock moth outbreak in progress in the Northwest during 1973. Arguments in favor of the use of DDT to control the epidemic are presented. These include the inability of any

other control practice to check the epidemic, the proved effectiveness of DDT against the tussock moth, and the danger of fire hazard from dead trees and a possible 30-60 year setback in the forest management of the region if the epidemic is left uncontrolled.
Control - 4

203. Neisess, J., G. P. Markin, and R. Schaefer. 1976. Field evaluations of acephate and Dimilin against the Douglas-fir tussock moth. J. Econ. Entomol. 69(6):783-786.

"Efficacy of acephate at 1.0 and 0.5 lb AI/2 gal per acre against Orgyia pseudotsugata (McDunnough) was compared to DDT at 0.75 lb AI/gal per acre on replicated 20-acre plots in 1974. Acephate at 1.0 lb AI/gal per acre and Dimilin [1-(4-chlorophenyl)-3-(2,6-difluorobenzoyl) urea] at 0.25 lb AI/gal per acre were evaluated on replicated 150-acre plots in 1975. In both experiments, all treatments caused significant reduction in larval populations. In 1974, the 1.0 lb acephate treatment resulted in population reductions that were comparable to the DDT treatment; however, the larval knockdown was faster for DDT. Both acephate and Dimilin provided excellent population control and foliage protection in 1975."
Control - 1, 2

204. Neisess, J., and M. J. Stelzer. 1975. Tests of microbial insecticides. West. For. and Conserv. Assoc., Perm. Assoc. Comm. Proc. 1974:15-16, Portland, Oreg.

Various formulations of a nucleopolyhedrosis virus (NPV) and Dipel, a commercial Bacillus thuringiensis were evaluated in 1973, against the Douglas-fir tussock moth. In the 1974 field season, a followup evaluation of the 1973 test was made to determine long-term effectiveness, and to investigate further new B.t. formulations and application strategies. The effectiveness of these tests is reported.
Control - 5, 6

205. Northwest Forest Pest ACTION Council and the College of Forestry, University of Washington. 1960. Douglas-fir tussock moth, Hemerocampa pseudotsugata McD. (Manual for) Forest Pest Short Course, March 23-25, 1960. Northwest For. Pest ACTION Council and Coll. For., Univ. Wash., Seattle. 3 p.

A description of the life cycle, physical characteristics, damage, and control of the Douglas-fir tussock moth is outlined.
General Background

206. Odera, J. A. 1972. A defoliator of pines, Orgyia hopkinsi (Lepidoptera: Lymantriidae) in Turbo, Kenya. Can. Entomol. 104(3):355-360.

"Sporadic outbreaks of many pine defoliators, including Orgyia hopkinsi Coll., have occurred in many pine plantations in Kenya in the last 20 years. A recent outbreak of O. hopkinsi is reported from young plantations in Turbo. Distribution, hosts, and epidemiology of the insect are discussed. The stages, life history, and habits are described. Eggs are laid on the bark close to pupation sites or on the pupal cases. The larvae feed on the foliage and pupate following the 5th instar." Migration occurs in the larval stage. Early instars are passively distributed by wind when they drop from trees by silken strands. Later instars actively migrate by crawling to nearby trees. The life cycle lasts 76-94 days with four generations per year. The generations overlap and larvae are present continuously. Two species of parasites, Pimpla mahalensis Grib. and Pimpla sp. (Hymenoptera: Ichneumonidae), have been recorded. Other factors of control are examined. A 2.5% solution of DDT is recommended for chemical control.
Related Material - 3

207. Ortiz, E., and J. Templado. 1975. Los cromosomas de cuatro especies de limantridos (Lep. Lymantriidae). [The chromosomes of four lymantriid species] EOS REV ESP Entomol. 49(1-4):225-232. [In Spanish.]

The results of a cytological study of four species of Lymantriidae, _Orgyia trigotephras_ Boisd., _Leucoma salicis_ L., _Lymantria dispar_ L., and _Euproctis chrysorrhoea_ L. are presented. The first and last species have not been studied before. All specimens are from central Spain. The geographical distribution, life cycle, and host of each species is briefly mentioned. The morphology and movement of chromosomes in mitosis and meiosis was studied in the larval, prepupal, and pupal stages in all four species. The chromosome numbers are as follows: _O. trigotephras_, n = 29; _Leucoma salicis_, n = 30; _Lymantria dispar_, n = 31; _E. chrysorrhoea_, n = 14. Although several species in the family Lymantriidae have been examined, the number is too small to make conclusive deductions on chromosomal variation in this group.
Related Material - 3

208. Page, M., and R. L. Lyon. 1973. Insecticides applied to western tussock moth reared on artificial diet: Laboratory tests. J. Econ. Entomol. 66(1):53-55.

"Eighteen insecticides were tested on 4th-instar larvae of _Hemerocampa vetusta_ (Boisduval). Eleven insecticides were highly toxic; pyrethroids were the most toxic. Six other insecticides gave toxicity indexes between 48 and 68. Four were slightly more toxic than DDT. Two of the insecticides killed less than 50% of the test population at the highest dose tested, 1,000 µg/g body weight. Although the western tussock moth has been reported to have five larval stages, six were observed. Larvae that molted to the 6th instar were usually female."
Related Material - 3

209. Palmer, L. 1976. Tussock moth report. Pac. Search 10(7):15.

A brief report on the status of the Douglas-fir tussock moth as a pest and the background of the Expanded Douglas-fir Tussock Moth Research and Development Program is presented. Some of the preliminary results of the program's researchers are given.
Related Material - 2

210. Patterson, J. E. 1938. Moths invade play area. West. Trees, Parks and For. 1:7.

An account is given of a 1935-37 infestation of Oslar's tussock moth, Hemerocampa oslari Banner, near the Mammoth Lakes in California. White-fir and Jeffrey pine were heavily defoliated, but red fir in the same stand was not attacked. The population crashed in 1937 from wilt disease and heavy predation.
Related Material - 3

211. Percy, J. E., E. J. Gardiner, and J. Weatherston. 1971. Evidence for a sex pheromone in female Orgyia leucostigma (Lepidoptera: Lymantriidae). Can. Entomol. 103(5):706-712.

"The results of behavioral, chemical, and histological studies are reported showing the presence of a sex attractant in female Orgyia leucostigma J. E. Smith. A method of bioassaying the attractancy of the female moths by the use of 4-ft-long glass tubes is given. Extraction of female abdominal tips with dichloromethane yields material biologically active when tested on male O. leucostigma.

"The pheromone producing gland is a dorsally situated, crescent-shaped structure formed by modification of the epidermal cells in the intersegmental membrane between the eighth and ninth abdominal segments. The glandular cells are goblet-shaped and are arranged in an unusual manner."
Related Material - 3

212. Perkins, R. F., and R. E. Dolph, Jr. 1967. Operational and entomological report on 1965 Burns project for Douglas-fir tussock moth control. USDA For. Serv. Pac. Northwest Reg. Insect Dis. Control Branch, Portland, Oreg. 28 p. Unpubl.

"The 1964 cooperative forest aerial survey recorded over 41,000 acres of true fir and Douglas-fir defoliated by the Douglas-fir tussock moth on the Malheur and Ochoco National Forests." A biological evaluation indicated an increasing population and that biological agents were not sufficient to control it. A control project was begun with aerial application of DDT. Discussed in this report are the operational procedures, logistics, personnel and equipment, contract obligations, spraying procedure, and the mortality of the tussock moth. Maps of the spray area are included. The project was described as a success.
Control - 2

213. Perlman, F., E. Press, J. A. Googins, A. Malley, and H. Poarea. 1976. Tussockosis: reactions to Douglas-fir tussock moth. Ann. Allergy 36:302-307.

"An unusually heavy infestation of the tussock moth resulted in a high incidence of symptoms affecting the skin and mucous membranes of those exposed to high concentrations of particulate matter of this insect. Extensive epidemiological studies proved these manifestations to be both toxic and allergic. The authors have given this condition the name, Tussokosis. Clinical and immunological studies including in vitro procedures and direct patient testing confirmed the allerginicity, as well as the nonspecific irritation of material from this moth."
Related Material - 1

214. Pierce, J. R. 1964. Douglas-fir tussock moth infestations in northern California - 1964. USDA For. Serv. Reg. 5, San Francisco, Calif. Unpubl.

Report unavailable.
Outbreaks - 2

215. Pierce, J. R. 1970. Biological evaluation. Douglas-fir tussock moth infestations in California - 1970. USDA For. Serv. Pac. Southwest Reg., San Francisco, Calif. 13 p. Unpubl.

Douglas-fir tussock moth infestations were detected in four areas of California in 1970; the largest was 100,000 acres, and the remaining three were of minor importance. White fir was the preferred host, but some damage was done to other species in the same stands. Sequential sampling was used to evaluate the population based on egg mass numbers. Of the 159 points sampled, 40 were in the threatening or intermediate class, in the largest infested area. Pupal parasitism was about 81%. Two of the smaller areas had increasing populations. Further sampling is recommended to evaluate the need for control measures. Testing of new control chemicals is also needed.
Outbreaks - 2

216. Portland Metropolitan Environmental Education Council (Tussock Moth Education Committee). [n.d.] The tussock moth issue. Portland Metrop. Environ. Educ. Counc., 59 p.

This is a simulation game about the current tussock moth control issue, geared for secondary schools. The process in this study is a series of activities focusing on a current environmental issue or situation. It was developed because of the need to engage students in the study of current problems and issues relating to environment and resource use. The activities combine the elements of role playing with a simulated decisionmaking process or simulation game.
Control - 4

217. Prebble, M. L., and K. Graham. 1945. The current outbreak of defoliating insects in coast hemlock forests of British Columbia. Part I. Description of outbreak and damage. B. C. Lumberman 29(2):25-24, 42, 44, 46, 48.

Conspicuous defoliation was first noticed in the hemlock forests in 1940 and 1941, in small scattered areas in the southern part of the coast regions of British Columbia. By 1943, defoliation was noticeable throughout the hemlock stands of southwest Vancouver Island. Up to and including 1944, the black-headed budworm has been the most numerous, widespread, and destructive forest pest but three other defoliating insects, including the western rusty tussock moth, increased in abundance

in 1944. The life cycle, gross morphology, hosts, distribution, and damage are given for all four insects. These populations are thought to build up in place instead of spreading localized infestations.
Related Material - 3

218. Priesner, E. 1975. Electroantennogram responses to female sex pheromones in five genera of Lymantriidae (Lepidoptera). Z. Naturforsch. Sect. C. Biosci. 30(5):676-679.

"Sex pheromones of European species of Lymantria, Euproctis, Stilpnotia, Orgyia, and Dasychira (Lymantriidae) have been cross-checked by recording male electroantennogram (EAG) responses to excised female pheromone glands. Within the same genus, there was invariably full reciprocity of the gland effects. Between different genera, however, in all species combinations investigated, the males strongly preferred their own species. From this pattern, it is concluded that the major pheromone constituents are different for the five genera. In accordance with these results, several species of Lymantria are either known or supposed to produce the same sexual attractant, cis-7,8-epoxy-2-methyloctadecane (disparlure), whereas for one species of Orgyia the sex pheromone was recently identified (Smith et al., Science 188.63 [1975]) as cis-6-heneicosen-11-one. None of the additional lymantriid pheromones have yet been chemically defined. In EAG screening tests, some species of this family were specifically responsive to hydrocarbons related to cis-7,2-methyloctadecene, the olefinic precursor of disparlure."
Related Material - 3

219. Richards, W. C., and Y. Hayashi. 1970. Detection of natural infection by cytoplasmic polyhedrosis virus (CPV) occurring in midgut cells of the white-marked tussock moth larvae. J. Invertebr. Pathol. 16:280-281.

The paper reports on a radiotracer technique to detect natural infection by cytoplasmic polyhedrosis viruses (CPV) in insects. The experimental insects used were field-collected larvae of Orgyia leucostigma from a population in which virus infection was suspected.

Fifth-instar larvae were fed on a synthetic diet containing uridine-3H to label the RNA of any developing virons. The midguts were dissected, incubated at 0-4°C for 30 days, and the material for analysis isolated by the method for CPV purification. The radioactive profiles and absorbance at 260 nm of free, uridine-3H-labeled CPV virions (control) and of the isolated material were compared. The absorbance peak of the isolated material was lower than the control, but the radioactivity profiles were similar. This gives evidence for a natural infection of CPV in O. leucostigma that can be detected by this method.
Related Material - 3

220. Riotte, J. C. E. 1967. Anmerkungen zur Nomenklatur einiger europäischer und nordamerikanischer Arten der Gattung Orgyia (Lepidoptera, Lymantriidae). [Remarks about the nomenclature of several European and North American species of the genus Orgyia (Lepidoptera, Lymantriidae).] Dtsch. Entomol. Z. 14(1/2):163-168. [In German.]

"The correct application of the specific names antiqua and recens in the lymantriid genus Orgyia is discussed. This was necessary because of frequent, recent confusion regarding the two species. The 'scarce vapourer' is Orgyia recens Hubner and the 'vapourer' is Orgyia antiqua Linnaeus as shown by Lempke (1950).

"The North American species of the genus Orgyia were separated into two genera first by Dyar (1897). The new genus, Hemerocampa, was erected on the basis that species were to be assigned to the genus if two pairs of spurs were present on the hind tibia. However, Dyar himself (1902) violated this system by incorrectly separating the species concerned into their respective genera. Thereafter no distinction has been made between Orgyia and Hemerocampa. Bryk (1934), Schauss In Seitz (1940), and McDunnough (1921 and 1938) treated all species concerned as Hemerocampa, except antiqua. Schauss made the additional error of saying that Hemerocampa had only one pair of spurs on the hind tibia, the opposite condition to Dyar's proposal, and thereby further confused the matter. Forbes (1948) seems to have arrived at a satisfactory solution to the problem by placing those species with two pairs of spurs on the hind

tibia in the subgenus Hemerocampa of the all-comprising genus Orgyia. The author is in agreement with this view.

"Here, dorsal tufts on the adult moths are used for the first time as a further criterion in assigning the species of Orgyia to the appropriate subgenus. The male genitalia are homogenous in both subgenera."
Related Material - 3

221. Roberts, P. H., and J. C. Evendon. 1949. Controlling the tussock moth. In Trees, USDA Yearbook of Agriculture 1949. p. 436-442. Washington, D.C.

The details of the control project initiated against the 1946-47 Douglas-fir tussock moth outbreak near Moscow, Idaho, are outlined. Included is a description of the life cycle, economic stage, and method of dissemination of the insect. The USDA Forest Service and the Bureau of Entomology and Plant Quarantine joint survey in late 1946 reported a present infestation of 350,000 acres and a potential loss of more than 100 million dollars if not controlled. Aerial application of DDT between May 20 and June 30, 1947, was recommended. The control project, administered by the USDA, included numerous government and private agencies. A total of 413,409 acres in Idaho and Washington were sprayed between May 22 and July 2, 1947. No live larvae were found in the treated area 1 week after spraying. Monitoring of the environmental impact of the DDT application by the Fish and Wildlife Service revealed no serious effects on birds, mammals, or fish, but a marked reduction in fish-food organisms occurred.
Control - 2

222. Robertson, J. L., L. M. Boetler, R. M. Russell, and N. E. Savin. 1978. Variation in response to insecticides by Douglas-fir tussock moth, Orgyia pseudotsugata (Lepidoptera: Lymantriidae), populations. Can. Entomol. 110(3):325-328.

"Selected insecticides were topically applied to different populations of the Douglas-fir tussock moth, Orgyia pseudotsugata (McDunnough). For each insecticide, the hypothesis of equal response curves was rejected by the likelihood ratio test. Even for two successive generations of the same populations, the hypothesis of equality was not accepted for some insecticides. Chemical control programs directed at different populations of this insect may be adversely affected by such variations."
Control - 1

223. Robertson, J. L., and R. L. Lyon. 1973. Douglas-fir tussock moth: contact toxicity of 20 insecticides applied to the larvae. J. Econ. Entomol. 66(6):1255-1257.

"Twenty chemicals were tested for their toxicity to 4th-instars of Hemerocampa pseudotsugata McDunnough. Eleven were more toxic than the standard mexacarbate, at both LD_{50} and LD_{90}." They are listed in decreasing order of toxicity at both LD_{50} and LD_{90}. "Data were also obtained on the effect of posttreatment holding conditions and on the effect of dye tracers and stabilizing adjuvants on the insecticidal activity of pyrethrins." Dyes and stabilizers do not affect the insecticidal activity of the pyrethrins used.
Control - 1

224. Roettgering, B. H. 1971. Biological evaluation. The Douglas-fir tussock moth in California - 1971. USDA For. Serv., San Francisco, Calif. 19 p. Unpubl.

In 1970, populations of the Douglas-fir tussock moth were detected in four separate stands of white fir in the Cascade and Sierra Nevada Mountain ranges. Evaluation of the infestations showed they would persist and in some locations increase in population in 1971.

In July 1971, a ground survey for early instar tussock moth larvae was conducted in fifteen areas with a history of Douglas-fir tussock moth activity, to detect incipient infestations. The survey employed Mason's

(1969) sequential sampling technique and a beating cloth technique to determine the presence or absence of the moth. Aside from the four infestations discovered in 1970, no unknown infestation with outbreak potential was detected.

Shortly after the 1971 survey, severe defoliation was detected on a total of 3,800 acres of white fir in two areas, and incipient infestations were discovered in three additional areas. Of the 11 population centers that formed in 1971, only two were found as part of the organized detection survey. All of the remaining were found by foresters and woods workers in conjunction with their work activities.

The 11 centers were surveyed in October-November of 1971. Egg masses were collected and sent to the USDA Forest Service laboratory at Corvallis, Oregon, for virus and egg viability reports. A resume of the information available on the classification of the Douglas-fir tussock moth populations in each of the 11 infested areas is given. The report makes several recommendations for further statewide surveys of tussock moth populations.

Outbreaks - 2

225. Roettgering, B. H. 1972. The Douglas-fir tussock moth in California - 1972. USDA For. Serv., San Francisco, Calif. 5 p. Unpubl.

This is a report on the continuation of the 1971 Douglas-fir tussock moth detection and population trend survey conducted in the white fir belt of the Cascade and Sierra Nevada Mountain Range in California. The 1972 survey season began in June and ended in September. Nine areas of infestation where the moth had caused noticeable damage were detected. Color aerial photographs of the infestations were taken in October to help evaluate the extent of the damage. Four areas were visited in November to survey overwintered egg masses and the extent of defoliation. Egg masses collected from these areas were sent to the Forestry Sciences Laboratory in Corvallis for disease diagnosis. Three maps detailing the position of the infestation area are appended.

Outbreaks - 2

226. Rohrmann, G. F. 1977. Characterization of N-polyhedrin of two baculovirus strains pathogenic for Orgyia pseudotsugata. Biochemistry 16(8):1631-1634.

"N-polyhedrin of inclusion bodies of two nucleopolyhedrosis viruses of Orgyia pseudotsugata were characterized. Alkali-dissolved N-polyhedrin from both virus strains was of similar size and consisted of a 12S molecule of 209,000 daltons. Eight subunits of about 26,000 daltons were found to form the 12S molecules. N-polyhedrin from both viruses showed two main antigens by immunodiffusion. The subunits appear to possess one antigen, and upon formulation of the 12S molecule, a new antigen is created. Both the subunit and 12S antigens from the two virus strains were shown to be antigenically related. The 12S molecule of both viruses also appears to possess a minor antigen unique to each virus."
Biology - 5

227. Rohrmann, G. F., and G. S. Beaudreau. 1977. Characterization of DNA from polyhedral inclusion bodies of the nucleopolyhedrosis single-rod virus pathogenic for Orgyia pseudotsugata. Virology 83(2):474-478.

"A nucleotide sequence complexity of 88.5×10^6 was determined for the DNA of the nucleopolyhedrosis single-rod (unicapsid) virus of Orgyia pseudotsugata using optical renaturation. In addition the genome size was determined to be 85×10^6 by comparison of EcoRl restriction endonuclease fragments with markers of known size using agarose gel electrophoresis. A G+C concentration of 44% for the viral DNA was estimated from its melting properties and buoyant density in CsCl. Evidence from buoyant density in CsCl indicates that DNA which is occluded in the polyhedral matrix but not associated with virions is of viral origin."
Biology - 5

228. Rohrmann, G. F., J. W. Carnegie, M. E. Martignoni, and G. S. Beaudreau. 1977. Characterization of the genome of the nucleopolyhedrosis bundle virus pathogenic for Orgyia pseudotsugata. Virology 80(2):421-425.

"By reassociation kinetics the DNA from the nucleopolyhedrosis bundle virus of Orgyia pseudotsugata was found to have a nucleotide sequence complexity of approximately $86X10^6$ daltons using both optical renaturation and S_1 nuclease assay to follow the renaturation. The molecular weight of the viral DNA by sedimentation analyses was determined to be $96X10^6$. The viral DNA has a T_m as 76.9° which corresponds to a guanine plus cytosine base composition of 54%."
Biology - 5

229. Rohrmann, G. F., R. H. McParland, M. E. Martignoni, and G. S. Beaudreau. 1978. Genetic relatedness of two nucleopolyhedrosis viruses pathogenic for Orgyia pseudotsugata. Virology 84(1):213-217.

"DNA from two nucleopolyhedrosis viruses pathogenic for Orgyia pseudotsugata showed no common patterns when restriction endonuclease fragments of both DNAs were compared by agarose-gel electrophoresis. Furthermore, DNA-DNA hybridization indicated at most 1% homology between DNAs from the two viruses."
Biology - 5

230. Ross, D. A., and J. Arrand. 1968. Douglas-fir tussock moth in British Columbia. Can. Dep. For., Insect and Dis. Surv., For. Pest Leafl. 9, 3 p. For. Res. Lab., Victoria, B.C.

This is a fact sheet on the Douglas-fir tussock moth in British Columbia that includes a brief history of outbreaks, list of hosts, area of distribution, description of the insect, its life history, a description of the damage, and methods of control. Malathion, 25% wettable powder at 2 lbs/100 gal of water is the recommended chemical control.
General Background

231. Ross, S. A., and D. Evans. 1954. Annotated list of forest insects of British Columbia, Part I - Lasiocampidae, Saturniidae, Liparidae. Entomol. Soc. B. C. Proc. 51:40-43.

"This is the first in a series of annotated lists of insects collected or reared by personnel of the Forest Insect Survey in British Columbia since 1937. . . . Precise collection localities are noted only where less than five scattered locality records are listed for a given species; otherwise, broad distribution categories are used. . . . Brief descriptions, generally of the full-grown larvae are included in the annotated list where such stages are known to one or both of the writers." Hemerocampa pseudotsugata is listed, along with a larval description and a brief history of outbreaks in British Columbia.
Taxonomy

232. Rossmoore, H. W., L. Elder, and E. A. Hoffman. 1970. Susceptibility of larvae of Hemerocampa leucostigma to several varieties of crystalliferous bacteria. J. Invertebr. Pathol. 16(1):102-106.

"Twelve isolates belonging to six H-antigen serotypes were evaluated for their effectiveness against Hemerocampa leucostigma larvae. All except one, Bacillus finitimus var. finitimus, produced high levels of mortality in four days. In addition, we found no difference in susceptibility to Bacillus thuringiensis var. thuringiensis among 1st- through 5th-instar larvae."
Related Material - 3

233. Rossmoore, H. W., and E. A. Hoffman. 1971. The effect of ^{137}Cs radiation on growth, development, and mortality of the larvae of the tussock moth, Hemerocampa leucostigma. J. Invertebr. Pathol. 17(2):277-281.

"Larvae and pupae of Hemerocampa leucostigma were irradiated in a ^{137}Cs Radcell and observed for effects on growth, development, and mortality. Irradiated larvae were half of control weight 10 days postradiation." No differences appeared in head-capsule size. "Although pupae were extremely resistant, relatively low doses to larvae prevented emergence. LD_{100} of first instars was 30 kr, while that of third instars was 85 kr. No delay in median time to pupation was noted."
Related Material - 3

234. Rossmoore, H. W., and E. A. Hoffman. 1971. The effect of gamma radiation on larval resistance to _Bacillus thuringiensis_ infection. J. Invertebr. Pathol. 17(2):282-283.

Some of the relations between radiation dose and the susceptibility of _Hemerocampa leucostigma_ larvae to _Bacillus thuringiensis_ infection are examined. Various combinations of radiation and spore-crystal dosages, route of administration, and variety of pathogen were used. No effect of radiation on susceptibility to _B.t._ was discerned. When postradiation time for bacteria infection was extended to 10 days, however, resistance to _B.t._ infection was depressed. Percent larval survival was 74.1 for the controls and 56.7 for the radiation-treated larvae.
Related Material - 3

235. Ruggles, A. G. 1917. The white marked tussock moth. Minn. Off. State Entomol. Circ. 42, 4 p. St. Paul, Minn.

The circular describes the white-marked tussock moth, _Hemerocampa leucostigma_, its life history, natural factors controlling its population, and a method of mechanical control by the physical removal of overwintering egg masses. The insect is cited as primarily a pest of shade trees.
Related Material - 3

236. Sager, S. M. 1958. Studies on the epizootiology of a virus disease in the Douglas-fir tussock moth, (_Hemerocampa pseudotsugata_ McD.). Interim Rep. Can. Dep. Agric., For. Biol. Div., For. Biol. Lab., Victoria, B.C. 27 p. Unpubl.

"The larval tussock moth population at Cascade, B.C., during the summer of 1955, appeared to be in an advanced stage of a polyhedrosis virus epizootic. A relatively high evidence of the disease was present in the young larvae and increased to 100% in samples of late-instar larvae. Other disease organisms and parasites were found in negligible amounts, but birds or other predators may have been effective in helping to reduce the larval populations. A survey at the end of the season

showed the number of cocoons to be extremely low, and the prediction seemed reasonable that the 1956 tussock moth population would be negligible.

"A high incidence of advanced virus infections in the early-instar larvae suggested that a certain proportion may have been transovarially infected; a later increase in incidence of infection may have been the result of larva-to-larva transmission of the disease. Regions of the Cascade outbreak with comparatively high larval densities showed slightly higher rates of infection and mortality from the virus than did areas of lower density. . . .

"Virus inclusion bodies found associated with ants and parasites in the Cascade outbreak area gave some evidence that these insects may act as a means of dissemination of the virus.

"Small scale virus dissemination tests were attempted and the results indicated that increasing the concentration of virus spray increased larval mortality."
Biology - 5; Control - 6

237. Sager, S. M. 1960. On the transtadial transmission of insect viruses. J. Insect Pathol. 2(3):307-309.

Observations on seven species of Lepidoptera indicate that complete transtadial transmission of insect viruses does occur in their respective hosts. Nuclear polyhedrosis and granulosis viruses were studied. In _Hemerocampa pseudotsugata_, _Orgyia antiqua_, and _Lambdina fiscellaria_, polyhedral inclusions were found in every stage except the egg. In _Hemerocampa_, this was confirmed by infectivity tests.
Biology - 5; Related Material - 3

238. Schreuder, G. F. 1977. An approach to evaluating effects of alternative controls for Douglas-fir tussock moth. Bull. Entomol. Soc. Am. 23(3):178-179.

The socioeconomic impact of a variety of control strategies, ranging from no control to the use of chemical or microbial controls are being incorporated into a model. The model concentrates on the impacts on wood production, the hydrological system, wildlife and fish, recreational activities, and fire incidence.
Control - 11

239. Schroeder, J. E. 1973. The Douglas-fir tussock moth: An impact statement relating to private lands in northeastern Oregon. Oreg. State For. Dep., Salem, Oreg. 17 p. Unpubl.

"This statement describes the impact of the Douglas-fir tussock moth infestation in northeastern Oregon as it has affected the State and privately owned lands for which the Department of Forestry has statutory responsibility." The problem is discussed in terms of the economic and aesthetic losses resulting from tussock moth defoliation.
Outbreaks - 5

240. Scribner, W. A. 1965. Report of operations. Potlatch tussock moth control project, 1965. State of Idaho Coop. Board For., Off. State For., Boise, Idaho. 29 p. Unpubl.

The planning, organization, and operation of the Potlatch tussock moth control project of 1965 is described. DDT at 3/4 lb/acre was applied to 86,533 acres of forest. Environmental monitoring was undertaken by the Fish and Game Department. Mortality of larvae was high, and the project was considered successful. Recommendations for improvement of control projects of this type are included.
Control - 2, 3

241. Shea, K. R. 1975. Progress on integrated pest management: Douglas-fir tussock moth, gypsy moth, and southern pine beetle. Soc. Am. For. Proc. 1975 Natl. Conv., p. 218-223. Washington, D.C.

The creation of the Combined Forest Pest Research and Development Program, its organization and administration, and its objectives, status, and plans are outlined. The cooperative effort to develop pest management systems for the Douglas-fir tussock moth, the southern pine beetle, and the gypsy moth is planned for completion within 3-5 years at an estimated cost of $46.8 million.
Related Material - 2

242. Shea, P. J. 1977. Testing of chemical and microbial insecticides for safety . . . some techniques. Bull. Entomol. Soc. Am. 23(3):176-178.

The effects of chemical and microbial insecticides on nontarget organisms have been examined for Bacillus thuringiensis, the Douglas-fir tussock moth nucleopolyhedrosis virus, Dimilin, Orthene, and Sevin-4-oil. Both laboratory and field tests were conducted using a variety of animals. The impact on terrestrial and aquatic insects, mammals, and birds was monitored using several techniques. The results of the studies on microbial insecticides indicate that neither B.t. nor the tussock moth virus poses a threat to the environment. The results of the chemical studies are not completely analyzed as yet.
Control - 1, 5, 6

243. Shepard, R. F. 1976. Douglas-fir tussock moth: Review of 1975-76 field experiments, pilot trials and operational projects, Kamloops, B.C. West. For. Conserv. Assoc., p. 67, Perm. Comm. Proc., Portland, Oreg.

In 1975-76, the Douglas-fir tussock moth polyhedrosis virus, Bacillus thuringiensis, Orthene, and Dimilin were field tested against the Douglas-fir tussock moth in Kamloops, B.C. Orthene was the most effective in preservation of new foliage, but its short residual life made timing of application critical. Dimilin achieved a greater population reduction but less foliage protection. The virus was very effective in population control, reducing it to innocuous levels. B.t. neither sufficiently

reduced the population nor provided foliage protection. The environmental impact of these control agents on nontarget organisms was examined.
Control - 1, 5, 6

244. Silver, G. T. 1962. Province of British Columbia, forest insect survey. Annu. Rep. For. Insect Dis. Surv. 1961, p. 107-119, Can. Dep. For., For. Entomol. and Pathol. Branch, Ottawa, Ont. Unpubl.

Among the various insects discussed, the Douglas-fir tussock moth was infecting part of the Okanagan Valley, with moderate to severe defoliation at some places. "Infestations include single isolated trees, small open-grown stands around agricultural buildings, and compact stands of Douglas-fir up to 20 acres in extent." Egg counts indicate that severe defoliation might occur in some stands in 1962. Mortality from a polyhedrosis virus infection was discovered in several late-instar larvae and pupae, on each of the larger infestations.

The rusty tussock moth was reported as being numerous on Vancouver Island.
Outbreaks - 2

245. Silver, G. T., and D. A. Ross. 1963. Province of British Columbia, forest insect conditions. Annu. Rep. For. Insect Dis. Surv., 1962, p. 107-123, Can. Dep. For., For. Entomol. and Pathol. Branch, Ottawa, Ont. Unpubl.

"The Douglas-fir tussock moth epidemic continued for the second successive year in the North Okanagan and at Hedley." Experimental control was carried out with DDT or malathion. Virus was sprayed from the ground and reduced the population considerably.
Outbreaks - 2; Control - 1, 2, 6

246. Smith, F. W. 1977. The effects of Douglas-fir tussock moth defoliation on stand dynamics. M.S. thesis. Univ. Wash., Seattle. 50 p. Unpubl.

Unavailable.
Outbreaks - 5

247. Smith, R. G., G. E. Daterman, and G. D. Daves, Jr. 1975. Douglas-fir tussock moth: sex pheromone identification and synthesis. Science 188(4183):63-64.

"The sex pheromone of the Douglas-fir tussock moth, Orgyia pseudotsugata (McD.), has been isolated and identified as (Z)-6-heneicosen-11-one. This compound and its E isomer have been synthesized and are highly potent in laboratory bioassays and field trials." At certain concentrations, the synthetic Z isomer was preferred over the extracted compounds of tussock moth females.
Biology - 2

248. Smith, R. G., G. D. Daves, Jr., and G. E. Daterman. 1975. Synthesis of (Z)-6-heneicosen-11-one. Douglas-fir tussock moth sex attractant. J. Org. Chem. 40(11):1593-1595.

"The synthesis of (Z)-6-heneicosen-11-one, the principal component of the sex attractant of the Douglas-fir tussock moth and the corresponding E isomer are described. The stereochemistries of the products were determined by selective reductions of the common intermediate, 6-heneicosyn-11-ol. The lower limits of isomeric purity of the products, determined by gas chromatographic analysis of the corresponding epoxides, was greater than 97% and 98% for the Z and E isomers, respectively."
Biology - 2

249. Sorenson, R. 1973. Between the devil and DDT: A report on the current tussock moth infestation. Pac. Search 8(3):12-15.

An analysis is presented of the controversy concerning the use of DDT to control the Douglas-fir tussock moth outbreak of 1972-73 in the Pacific Northwest. The life history of the insect, biological control agents, the cyclic pattern of outbreaks, and the insect's capacity for destruction are briefly outlined. The history of the present infestation and the pros and cons of the EPA refusal to grant the USDA Forest Service request for emergency use of DDT are explored.
Control - 4

250. Sower, L. L., and G. E. Daterman. 1977. Evaluation of synthetic sex pheromone as a control agent for Douglas-fir tussock moths. Environ. Entomol. 6(6):889-892.

"Synthetic pheromone evaporated from controlled-release applicators substantially reduced the ability of male Douglas-fir tussock moth, _Orgyia pseudotsugata_ (McDunnough), to locate females and mate in the field. Dosages of 0.05-5.0 mg/ha/day were tested; the 2 strongest treatments of 1.0 and 5.0 mg/ha/day were the most effective. The disruption effect was relatively greater with traps baited with live females than with traps baited with synthetic pheromone. Catches of males in traps increased with increased height of traps above the 1.5-m treatment level up to 18.3 m."
Biology - 2, Control - 10

251. Stairs, G. R. 1971. Use of viruses for microbial control of insects. _In_ Microbial control of insects and mites, p. 97-124. H. D. Burges and N. W. Hussey, ed. Acad. Press, London and New York.

The host-virus relations and the use of viruses in both long-range and short-range pest control is discussed for several important pest species. A brief paragraph on the Douglas-fir tussock moth mentions the susceptibility of the larvae to a nucleopolyhedrosis virus. Attempts at testing NPV control of the tussock moth larvae were hampered by the presence of an epizootic in the test population. Sufficient information

was obtained to indicate that epizootics can be initiated in incipient outbreak populations.
Control - 6

252. Stark, R. W. 1973. Statement. Symposium on the status of knowledge on the Douglas-fir tussock moth. EPA, Nov. 16, 1973, p. 106-115, Seattle, Wash.

Although the Douglas-fir tussock moth is one of the most destructive defoliators in the Western United States, only 26 scientific papers have been written on it, and only 6 of these deal with basic research. The author concludes that the tussock moth should be given a higher research priority. Four areas of knowledge need extensive research; the impact of damage to the forest and economy, the population dynamics, regulatory tactics and strategies, and the development of an integrated pest management program. He believes a commitment from the USDA Forest Service and the EPA for a sustained research program is needed.
Related Material - 2

253. Steinhaus, E. A. 1951. Report on diagnosis of diseased insects, 1944-1950. Hilgardia 20(22):629-678.

This paper presents a general and summarized report on the diagnosis for 575 accessions of dead and diseased insects, plus 27 accessions of healthy insects examined for symbiotes, received at the Laboratory of Insect Pathology, Division of Biological Control, in Berkeley, California, between August 1, 1944, and December 31, 1950.

Several new species of viruses, bacteria, fungi, protozoa, and symbiotes are recorded. The findings of some small research projects include: observations of several new and previously recognized virus infections; results of an attempt to grow insect viruses in embryonated hen eggs; reisolation and redetermination of the bacterium responsible for widespread epizootics among grasshoppers; a reevaluation of the pathogenic effects of so-called *Bacillus* "C" for scale insects; new host and locality data for several important entomophagous fungi and protozoa;

and new records regarding certain intracellular and caecal symbiotes of insects.

The Douglas-fir tussock moth larvae sent from Troy, Oregon, suffered from polyhedral virus infection.
Biology - 5

254. Steinhaus, E. A., and G. A. Marsh. 1962. Report of diagnoses of diseased insects, 1951-1961. Hilgardia 33(9):349-490.

This report presents the findings of laboratory diagnoses of diseased insects during the period of January 1, 1951, to December 31, 1961. The diagnoses reported are brief statements as to the source of the diseased insect and the etiology of its disease. A new approach to diagnosis uses more precise procedures, more detailed forms for recording data, and a more efficient method of collecting data. Douglas-fir tussock moth larvae were found to have polyhedrosis virus in two out of five samples analyzed.
Biology - 5

255. Stelzer, M. J. 1972. Epizootiological investigation. Part IV. In Results of field experiments for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus and associated studies. USDA For. Serv. Prog. Rep., 8 p. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. Unpubl.

"An aerial application of the polyhedrosis virus of the Douglas-fir tussock moth was tested in 1971 on the Eldorado National Forest. The virus was applied by helicopter at a dosage of 100 billion polyhedra in 1 gal of a water-based formulation per acre. Two plots, each of about 40 acres in area, were sprayed.

"Periodic posttreatment evaluations showed only low levels of virus mortality, ranging from 2-12% of the larval population, resulted from the treatment. Inadequate spray coverage, improper timing, and inactivation

of the virus by ultraviolet radiation are postulated as the causes for the low rates of infection induced by the treatment.

"An assessment of surviving tussock moth population on the Eldorado National Forest is essential to determine whether or not the virus becomes established or provides effective control in 1972."
Control - 6

256. Stelzer, M., J. Neisess, J. C. Cunningham, and J. R. McPhee. 1977. Field evaluation of baculovirus stocks against Douglas-fir tussock moth in British Columbia. J. Econ. Entomol. 70(2):243-246.

"Aerial applications of three baculovirus stocks were tested against Orgyia pseudotsugata (McDunnough) in British Columbia in June 1975. A dosage of 100 billion polyhedra/acre, formulated in a molasses and a nonmolasses formulation and applied at 1 or 2 gal/acre, provided population control and excellent foliage protection. Larvae collected from the treated areas 5 days after spraying showed virus infection rates that ranged from 60-87%. With the exception of one treatment that was applied under extremely adverse meteorological conditions there were no significant differences between virus treatments. Population densities were reduced by more than 90% at 21 days posttreatment, and no evidence of survival to the pupal stage was found on the virus-treated areas."
Control - 6

257. Stelzer, M. J., J. Neisess, and C. G. Thompson. 1975. Aerial application of nucleopolyhedrosis virus and Bacillus thuringiensis against the Douglas-fir tussock moth. J. Econ. Entomol. 68(2):269-272.

"Efficacy of application of a nucleopolyhedrosis virus (NPV) and Dipel (Bacillus thuringiensis Berliner) against Orgyia pseudotsugata (McDunnough) was determined on replicated field plots of 20 acres in size. Population reductions exceeded 95% at 35 days on plots treated with NPV dosages of 100×10^9 and at 100×10^{10} polyhedra/acre in 2 gal/acre of 25% molasses formulation. Application of Dipel at 1 lb/acre in 25% molasses was as effective as the NPV. These treatments also

provided excellent foliage protection, with estimated defoliation below 25%. In contrast, Dipel formulated in Biofilm failed to reduce larval densities to a satisfactory level or to prevent severe defoliation."
Control - 5, 6

258. Stevens, R. E. 1957. Control of an infestation of the Douglas-fir tussock moth with DDT aerial spray. Calaveras and Tuolumne Counties, California. USDA For. Serv., Calif. For. and Range Exp. Stn., Berkeley, Calif. 13 p. Unpubl.

An aerial spray operation was implemented on July 31 and August 1 and 2, 1956, for control of the Douglas-fir tussock moth in Calaveras and Tuolumne Counties, California. Nearly 10,000 acres were sprayed with DDT in seven separate units. The infestation was closely monitored in 1955 to determine the need for control in 1956. "Postspray appraisals, based primarily on assessment of feeding damage and an intensive search for new egg masses, indicated that satisfactory control was achieved."
Control - 2

259. Strickler, G. S. 1975. DDT residue accumulation and decline in kidney fat of lambs grazing sprayed forest range. USDA For. Serv. Res. Note PNW-256, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"DDT residues in fat of weaner lambs grazing 1, 2, 6, 10, and 14 weeks (five treatment groups) in forests sprayed with DDT for Douglas-fir tussock moth control increased rapidly up to 2 weeks, then decreased. After removal of lambs to unsprayed feed for 14 to 22 weeks, fat residues declined, but only those in the 1- and 2-week treatments fell significantly below the 5 ppm tolerance level."
Control - 3

260. Strickler, G. S., and P. J. Edgerton. 1970. Monitoring DDT residues on forage plants following a forest insect control program. Pestic. Monit. J. 4(3):106-110.

"The amount of DDT reaching understory vegetation grazed by cattle, deer, and elk, and the DDT residues in herbage samples of sedge, lupine, and sagebrush were determined for one prespray and three postspray sampling dates up to 1 year following aerial application of DDT for forest insect control. The DDT was applied at the start of the livestock grazing period. Ground-level DDT dosage ranged from 3-78% of the designated 3/4 lb/acre rate. . . . Residue in species plot samples from the first two postspray dates were significantly related to ground-level dosage. Cycling of DDT was not indicated; a greater elk sedge residue 1 year after spraying was attributed to differences in sampling. Associated DDT residues in cattle and big game are briefly discussed."
Control - 3

261. Stoszek, K. J. 1977. Factors influencing tree and stand susceptibility to Douglas-fir tussock moth attack. Bull. Entomol. Soc. Am. 23(3):171-172.

A report on studies undertaken in 1972-74 to determine the probability that a given stand will suffer defoliation by the Douglas-fir tussock moth. Both ground and aerial survey procedures were used to assess the physiographic edaphic and phytoceonotic characteristics of the site; and the species composition, structure, and vigor of the stand. Preliminary results indicate that: stands on ridge tops and upper slopes have significantly higher defoliation; defoliation increased with tree age; and grand fir was more susceptible to defoliation than Douglas-fir. Several other factors, such as aspect, elevation, canopy structure, and number of stories also influence the probability of tussock moth defoliation.
Outbreaks - 5

262. Sugden, B. A. 1957. A brief history of outbreaks of Douglas-fir tussock moth, _Hemerocampa pseudotsugata_ McD., in British Columbia. Entomol. Soc. B. C. Proc. 54:37-39.

Douglas-fir tussock moth outbreaks are listed and analyzed. Results of analysis indicate outbreaks have recurred at intervals in a limited part of B.C., mostly in open-grown stands of Douglas-fir. They build up quickly in a few suitable sites, last for a short period, and then collapse. In a few localities where an outbreak has never been recorded, a small population always persists.
Outbreaks - 1

263. Swaine, J. M. 1917-1918. The control of the white-marked tussock moth. Rep. Soc. Prot. Plants, 10 p. (On file: Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg.)

The white-marked tussock moth is a serious native defoliator of hardwoods in the Mountain Provinces of Canada. An outbreak was expected the summer of 1918 [after this report]. A description of the stages of the moth's life cycle, the life history, and type of injury of the moth is given. Preventive control, i.e., maintaining healthy trees, is listed as the primary means of controlling the white-marked tussock moth. The egg and larval stages are the best targets for applications of artificial control. Destruction of egg masses during dormant months is an effective control method, as is spraying the larvae with arsenate compounds. Banding the trees with tanglefoot will prevent reinfestation from any wandering larvae.
Related Material - 3

264. Swaine, J. M., and G. E. Sanders. 1918. The white-marked tussock moth and its control on shade trees and ornamental trees. Can. Dep. Agric. Entomol. Branch, Circ. 11, 12 p.

The white-marked tussock moth can be controlled by destroying the egg masses, either by removal or painting with creosote, and by spraying larvae with arsenate compounds and banding the trees with sticky tape to prevent larval migration. For control in orchards, a paste of lead arsenate or arsenate of lime is used. A description of the life stages and biology of the moth is included.
Related Material - 3

265. Tarrant, R. F., D. G. Moore, W. B. Bollen, and B. R. Loper. 1972. Pesticides in soil. DDT residues in forest floor and soil after aerial spraying, Oregon--1965-68. Pestic. Monit. J. 6(1):65-72.

"One month after aerial application of DDT (12 oz/acre) to an eastern Oregon forest, 3 oz/acre of DDT residues (DDT, its isomers and metabolites--DDD, DDE, p,p'-DDT, and o,p'-DDT) were detected in the forest floor; 3 years later, the DDT content had decreased by more than 50%, and had not leached into the surface mineral soil.

"At the time of spraying, water from two streams draining the sprayed area had a total DDT content of about 0.3 ppb. This low concentration decreased rapidly to levels below limits of analytical detection. No effect of the spraying was noted on soil microbial populations, nitrification rate, or amount of nitrate nitrogen in the soil.

"Of the 12 oz of DDT applied per acre, about 26% reached the ground surface initially; and over 36 months, about 6% more was brought to the ground in litterfall. Thus, approximately one-third of the sprayed chemical reached the forest floor. The need for more efficient aerial methods of chemical application is evident."
Control - 3

266. Teakle, R. E. 1973. A nuclear polyhedrosis virus of the painted apple moth (Orgyia anartoides (Walker)). Queensland J. Agric. Anim. Sci. 30(2):179-190.

"A disease of the painted apple moth (Orgyia anartoides (Walk.)) caused by a nuclear-polyhedrosis virus was investigated. The virus is described on the basis of its morphology and pathology and the influence of larval age and size of virus dosage on incubation period." In tests of cross-infectivity, viruses from O. anartoides and O. australis demonstrated identical serological reactions and reciprocal cross-infectivity.

"The nuclear polyhedrosis virus studied in the current work is a virulent pathogen. The habit of O. anartoides of depositing eggs in clumps and the gregarious tendency displayed by early instar larvae favors early cross-transmission of the virus." Larvae of early instars are more susceptible to the virus. Cross-transmission is favored by the lack of mobility of the wingless female adult. Thus the distribution of this insect is usually restricted to individual trees.
Related Material - 3

267. Templado, J. 1974. Biological observations on Orgyia trigotephras Biosd. (Lep., Lymantriidae). Bol. Estac. Cent. Ecol. 3(6):63-67.

Article unavailable.
Related Material - 3

268. Terrell, T. T. 1955. Douglas-fir tussock moth outbreak in northeastern Washington. Season of 1955. USDA For. Serv. Intermt. For. and Range Exp. Stn., Missoula, Mont. 3 p. Unpubl.

An infestation of the Douglas-fir tussock moth which had been moderately active for several years in northeastern Washington, developed into a serious outbreak in 1955. In September, 1955, an aerial survey was made of the infested Douglas-fir forests by the Missoula Forest Insect Laboratory. Stevens County contained the heaviest infestations, with small scattered spots of infestation in Spokane and Pend Oreille Counties. "Altogether, 87 separate areas of infestation, ranging from single infested trees to as much as 2,000 acres of tree defoliation, were mapped during the flights." The history of the infestation, and the methods used to survey damage are presented.
Outbreaks - 2

269. Thomas, J. W., and D. C. McClusky. 1974. Effects of aerial application of DDT for tussock moth control on nestling survival of mountain bluebirds and house wrens. USDA For. Serv. Res. Pap. PNW-185, 37 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The EPA approval of the use of DDT against the Douglas-fir tussock moth in 1974 was contingent upon intensive environmental monitoring to determine the impact on nontarget organisms. The present study was undertaken to assess if DDT application had adverse, short-term effects on reproductive performances of insectivorous birds. The study was limited to cavity-nesting, insectivorous birds such as mountain bluebirds, western bluebirds, and house wrens.

Birds were encouraged to nest in specially constructed nest boxes in spray and nonspray areas. The boxes were checked at intervals from 2-21 days to determine: clutch size, condition of eggs; number of young hatched, their condition and approximate age; and number of young fledged. Reproductive success was measured by comparisons of mean number of eggs per clutch, egg fertility, nestling mortality, and number of young fledged between spray and nonspray areas.

DDT reaching the ground was monitored with oil-sensitive cards in the spray area only.

No detrimental, short-term effects on clutch size or nestling survival of the selected species of birds were detected by this study.
Control - 3

270. Thompson, C. G. 1966. Tests to determine effectiveness of different virus dosages and concentrations. In Results of test to develop operational procedures for controlling Douglas-fir tussock moth with aerial application of polyhedral virus spray. USDA Agric. Res. Serv. and For. Serv., Portland, Oreg. 27 p. Unpubl.

"A simulated field test was conducted during the summer of 1965 to determine virus spray dosage and concentrations required for control of the Douglas-fir tussock moth. Specific objectives were to determine the effectiveness of three different virus polyhedra rates applied by helicopter in 1 gal and in 3 gal of spray per acre. The optimum timing of application was also investigated. Spray was applied by helicopter at

5-weekly intervals to potted trees, which were subsequently colonized with larvae to determine pathogenicity of the different treatments. . . .

"Applications of 1, 5, and 50 billion polyhedra in 1 gal/acre were as effective, or slightly better, than applications of the same virus rates in 3 gal/acre. The applications were more effective with increasing virus rate. Only the rate of 50 billion polyhedra per acre was sufficiently effective to indicate a satisfactory control potential. Applications were most effective against 2nd-instar larvae. Larvae from egg masses collected in northern California were apparently more susceptible to infection on Douglas-fir than on grand fir.

"Following an initial wave of polyhedrosis resulting directly from virus applications, waves of polyhedrosis occurred at about 2-week intervals. These latter waves were apparently due to natural contagion and spread of the disease from those dying as a direct result of the application."
Control - 6

271. Thompson, C. G. 1975. Comparison of environmental stresses between field and insectary populations. In Baculoviruses for insect pest control: Safety considerations, p. 158. M. D. Summers, R. Engler, L. A. Falcon, and P. V. Vail, eds. Am. Soc. Microbiol.

Two comments are offered concerning the use of virus for Douglas-fir tussock moth control. First, the amount of virus applied for control is minimal compared to the amount naturally produced by the larvae moth during an epizootic. Secondly, the stress on laboratory-reared insects is much less than the stress suffered by field populations. Thus the possible favoring of mutant virus strains from laboratory-stressed insects can be discounted.
Biology - 5; Control - 6

272. Thompson, C. G., J. Neisess, and H. O. Batzer. 1977. Field tests of Bacillus thuringiensis and aerial application strategies on western

mountainous terrain. USDA For. Serv. Res. Pap. PNW-230, 12 p. Pac. Northwest For. Range Exp. Stn., Portland, Oreg.

Control - 5, 8

273. Toliver, M. E. [n.d.] Bionomics of egg parasitoids of the Douglas-fir tussock moth in the Southwestern United States. Unpubl. Lit. Rev. Study Plan (On file: Rocky Mt. For. and Range Exp. Stn., Albuquerque, N.M. 34 p.

The primary objective of the study plan presented is the determination of the role of egg parasitism by Telenomus californicus and Baryscapus sp. in endemic and epidemic populations of the Douglas-fir tussock moth in the Southwest. The secondary objectives include: determination of egg parasites and other mortality factors acting on the Douglas-fir tussock moth in the Southwest, description of the life history of T. californicus and Baryscapus sp., determination of effects of egg mass exposure on parasitism, description of the parasite-parasite interactions, description of parasite-host interactions, and the determination of effects of Bacillus thuringiensis and nucleopolyhedrosis virus on T. californicus and Baryscapus sp.

The study plan contains a detailed literature review covering the Douglas-fir tussock moth life history, natural enemies, and history of outbreaks.

A research schedule and cost estimates are included.

Biology - 3

274. Torgersen, T. R. 1977. Identification of parasites of the Douglas-fir tussock moth, based on adults, cocoons and puparia. USDA For. Serv. Res. Pap. PNW-215, 28 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"A key for the identification of egg, larval, and pupal parasites of the Douglas-fir tussock moth is supplied. Determinations are based on features of adult parasites, their cocoons, or puparia. Notes on additional diagnostic characters and biologies are also given."
Biology - 3

275. Tucker, R. K., and D. G. Crabtree. 1970. Handbook of toxicity of pesticides to wildlife. U.S. Resour. Publ. No. 84, p. 88-89.

The acute oral toxicity summary of the nucleopolyhedrosis virus of the Douglas-fir tussock moth is presented. LD_{50}s for mallard ducks, pheasants, house sparrows, albino rabbits, and mule deer are given.
Control - 6

276. Tunnock, S. 1962. Biological evaluations of three Douglas-fir tussock moth infestations in northern Idaho, 1961. USDA For. Serv., Div. State and Priv. For. Reg. 1, Missoula, Mont. 7 p. Unpubl.

Cocoon samples were collected from three infested sites in northern Idaho to determine the status of the infestation. Cocoons were examined for egg masses, adult emergence, and pupal mortality. High ratios of current egg masses to older masses in two areas indicated a probable population increase for 1962. Female moths were slightly more abundant than males in all three areas. Dipterous parasites were found inside pupae more frequently than hymenopterous parasites.
Outbreaks - 2

277. Tunnock, S. 1963. Douglas-fir tussock moth infestations in northern Idaho and northwestern Montana, 1963. USDA For. Serv., Div. State and Priv. For. Reg. 1, Missoula, Mont. 5 p. Unpubl.

In October 1963, biological evaluations of several Douglas-fir tussock moth infestation sites in Montana and Idaho were made to determine their growth potential for 1964. Cocoon samples were collected to determine: ratio of old to current egg masses, successful adult emergence, causes of pupal mortality, and percent and kind of

parasitization. The probable infestation trends for 1964, based on percentages of current egg masses and pupal mortality, are presented for each infestation site.
Outbreaks - 2

278. Tunnock, S. 1963. Trends of Douglas-fir tussock moth infestations in northern Idaho and Colbert, Washington, 1962. USDA For. Serv., Div. State and Priv. For. Reg. 1, Missoula, Mont. 7 p. Unpubl.

Aerial surveys of nine centers of Douglas-fir tussock moth infestation in northern Idaho and northeastern Washington were made in 1962 to determine the extent of defoliation. Biological evaluation of the tussock moth population intensity was made during October to determine the population trend for 1963. Cocoon samples were collected and examined for egg masses, adult emergence, and causes of pupal mortality. Dipterous parasites were found inside pupae more often than hymenopterous parasites.

Population trends for each area are listed individually, based on the percentage of current egg masses and on pupal mortality.
Outbreaks - 2

279. Tunnock, S. 1964. Status and trends of Douglas-fir tussock moth infestations in northern Idaho and northwestern Montana. USDA For. Serv., Div. State and Priv. For. Reg. 1, Missoula, Mont. 10 p. Unpubl.

Biological evaluations of the major Douglas-fir tussock moth outbreaks in Idaho and Montana were made during October 1964 to determine their status and trend in 1965. Cocoon samples were examined for percent of current to old egg masses and pupal mortality. The results are listed in tabular form for each infestation site.

A history of tussock moth outbreaks in the Northwest and a summary of the life history of the moth is included.
Outbreaks - 2

280. Tunnock, S. 1965. Evaluation of Douglas-fir tussock moth infestations in northern Idaho and northwestern Montana, 1965. USDA For. Serv., Div. State and Priv. For. Reg. 1, Missoula, Mont. 5 p. Unpubl.

"Douglas-fir tussock moths caused various degrees of defoliation during 1965 in 50 acres south of Polson, Montana; in three 10- to 40-acre areas south of Elmo, Montana; and within 225,000 acres in Benewah and Latah Counties, Idaho. These infestations were examined during October 1965 to determine the ratio of current egg masses to old and to evaluate the effects of natural mortality factors. No current egg masses were found in Montana and only a few were collected in Idaho. Observations showed that the infestations had died out. Factors responsible for this were nuclear polyhedrosis virus, parasites, and aerial applications of DDT in Idaho."
Outbreaks - 2

281. Tunnock, S. 1966. A pilot test to control Douglas-fir tussock moth by an aerial application of nuclear polyhedrosis virus during 1965. USDA For. Serv., Div. State and Priv. For., Reg. 1, Missoula, Mont. 17 p. Unpubl.

"The effectiveness of a nuclear polyhedrosis virus obtained from diseased Douglas-fir tussock moth larvae was tested during the summer of 1965. A helicopter was used to spray 1,220 acres at the rate of 1 billion polyhedra in 1 gal of water per acre when most larvae were 2nd instars. Larvae, collected before treatment and at weekly intervals after treatment, were reared on artificial media in plastic cups at an insectary until they died from polyhedrosis, were killed by other agents, or emerged as adults.

"Mortality from polyhedrosis was consistently higher in an untreated area than in a treated area. Therefore, the application of 1 billion polyhedra per acre did not significantly decrease the Douglas-fir tussock moth population. Mortality from other diseases, parasites, and unknown agents was not above 17.6% during any of the collection periods.

Hymenopterous and dipterous parasites caused most of this mortality. Five species of wasps killed 96.7% of the parasitized larvae.

"Some adult emergence occurred in each collection. However, many adults were malformed, which indicated that they may have been infected with virus. No current egg masses could be found in treated and untreated areas during the fall of 1965."
Control - 6

2. Tunnock, S. 1973. The Douglas-fir tussock moth in the northern region. A cartographic history of the outbreaks from 1928 to 1973. USDA For. Serv., Div. State and Priv. For., Missoula, Mont. Report 73-27, 18 p.

"The Douglas-fir tussock moth, Orgyia pseudotsugata (McD.), periodically defoliates Douglas-fir, true firs, and other host trees in forests of the United States. In the northern region, these infestations occur about once every decade.

"This history covers the earliest recorded outbreak in northeastern Washington from 1928 to 1930 and includes information about outbreaks in northern Idaho and eastern Washington from 1944 to 1947, northeastern Washington and northern Idaho from 1950 to 1955, northern Idaho and western Montana from 1961 to 1975, and the current outbreak in northern Idaho, northeastern Washington, and western Montana which began in 1970.

"These outbreaks usually last from 2-4 years in forested areas and typically go through a buildup phase the 1st year, an outbreak phase the 2nd year, and a declining phase the 3rd year due to parasites and/or polyhedrosis virus. Exceptions are: It may take an outbreak 2 years to build up, or occasionally natural control agents can cause a population collapse at the end of the 2nd year."
Outbreaks - 1

283. Tunnock, S. 1974. Impact of egg viability, egg parasitism and virus on 1974 Douglas-fir tussock moth defoliation potential in western Montana. USDA For. Serv. North. Reg. Insect and Dis. Rep. 74-11. 4 p. Div. State and Priv. For., Missoula, Mont.

"Douglas-fir tussock moth egg mass studies during winter 1974 indicate that natural factors such as low egg viability, egg parasitism, and virus do not alter the potential for heavy defoliation in two sections south of Frenchtown and one section northwest of Lolo, Montana." The percent virus infection was low from the egg masses and ranged from 1.0 to 5.3. More than 30% virus in an area is needed to classify it as a low risk from the standpoint of potential damage.
Outbreaks - 2

284. Tunnock, S. 1975. Impact of egg viability, egg parasitism, and virus on 1975 Douglas-fir tussock moth defoliation potential in the lower Flathead Valley, Montana. USDA For. Serv. North. Reg. For. Environ. Prot. Rep. 75-9, 7 p. Div. State and Priv. For., Missoula, Mont.

"Evaluation of Douglas-fir tussock moth, Orgyia pseudotsugata, egg masses collected from an outbreak area in the lower Flathead Valley indicated that overall egg viability was relatively high, egg parasitism was low, and virus infestation averaged 7.1% northwest of Polson, 17.9% south of St. Ignatius, and 57.0% west of Ravalli. In the three areas, a total of 2,240 acres may be visibly defoliated in 1975, and light defoliation may be scattered over an additional 5,600 acres. The outbreak is expected to decline due to natural causes by the end of 1975."
Outbreaks - 2

285. Tunnock, S., J. E. Dewey, S. Kohler, and S. Hagland. 1974. Evaluation of a Douglas-fir tussock moth outbreak in the lower Flathead Valley, Montana. USDA For. Serv. North. Reg. Insect and Dis. Rep. 74-24, 10 p. Div. State and Priv. For., Missoula, Mont.

"An aerial survey during 1974 revealed approximately 5,000 acres of various degrees of Douglas-fir tussock moth, Orgyia pseudotsugata McD., defoliation in the lower Flathead Valley. An egg mass survey was made in September to determine the potential for damage in 1975." The number of new egg masses/1,000 in^2 of foliage, the ratio of old to new egg masses, and the number of cocoons per egg mass were calculated. Plots containing 0.1 or more new egg masses/1,000 in^2 of foliage were considered "high risk", and control may be advisable. Based on the survey, significant defoliation was predicted on 2,880 acres.
Outbreaks - 2

286. Tunnock, S., J. E. Dewey, R. Lood, and R. L. Livingston. 1973. Status of Douglas-fir tussock moth infestations in the northern region, 1973. USDA For. Serv. North. Reg. Insect and Dis. Rep. 73-23a, 9 p. Div. State and Priv. For., Missoula, Mont.

Aerial surveys of Douglas-fir tussock moth infestation sites in Washington, Idaho, and Montana were conducted in July-August of 1973 to detect the extent of defoliation. The surveys revealed a total of 127,000 acres of aerially visible damage. Damage occurred in two separate patterns. Most of the outbreaks were characterized by partial defoliation of varying intensities occurring over entire hillsides or stands. The stands were predominately grand fir. The other type of infestation associated with pure stands of young Douglas-fir, was characterized by heavily defoliated clusters of trees (1/2-50 acres); some almost completely defoliated.

Maps of defoliated areas are included.
Outbreaks - 2

287. Tunnock, S., and R. L. Livingston. 1974. Potential Douglas-fir tussock moth damage in northern Idaho in 1974 based on a 1973 fall egg mass survey. USDA For. Serv. North. Reg. Insect and Dis. Rep. 74-4, 26 p. Div. State and Priv. For., Missoula, Mont.

"An epidemic of the Douglas-fir tussock moth was detected in northern Idaho in 1972. In 1973, aerial surveys showed that nearly 100,000 acres contained various degrees of visible defoliation. An egg mass survey of five reporting units made in the fall of 1973 determined potential for damage in 1974. Based on new egg mass densities and new-to-old egg mass ratios, damage is predicted to be sufficiently high to warrant control on 34,138 acres in the Coeur d'Alene unit, 64,779 acres in the St. Joe unit, 4,433 acres in the Clearwater unit, 4,762 acres in the Craigmont unit, and 33,501 acres in the NezPerce unit. Total acres qualifying for treatment are 141,613. In addition, some damage might occur on 81,554 acres within the five units. These areas will be further evaluated to determine if they qualify for treatment."

Outbreaks - 2

288. Tunnock, S., R. L. Livingston, and W. E. Bousfield. 1974. Impact of egg viability, egg parasitism, and virus on 1974 Douglas-fir tussock moth defoliation potential in northern Idaho. USDA For. Serv. North. Reg. Insect and Dis. Rep. 74-9, 10 p. Div. State and Priv. For., Missoula, Mont.

Egg masses collected fall 1973 in northern Idaho were studied to assess the effects of egg viability, egg parasitism, and virus infection on the defoliation potential of the area. Egg masses were stored overwinter and incubated in February; the surviving larvae were reared. Dead larvae were examined for virus polyhedra. The percent nonviable eggs ranged from 0.3-68.9, and egg parasitism ranged from 0-14.9% (two species of Hymenoptera were recovered). Virus incidence was generally low. The acreage to be treated for tussock moth control was adjusted according to the findings of this survey.

Outbreaks - 2

289. U.S. Department of Agriculture. Douglas-Fir Tussock Moth Program. 1975. Douglas-Fir Tussock Moth Newsletter.

The Douglas-Fir Tussock Moth Newsletter is a monthly publication covering the current activities of the program. It includes reports on program meetings, a calendar of events, progress reports on tussock moth research, reports on current research on other forest pests, lists of recent publications, and articles on program personnel.
Related Material - 2

290. U.S. Department of Agriculture, Agricultural Research Service and Forest Service. 1966. Results of tests to develop operational procedures for controlling Douglas-fir tussock moth with aerial application of polyhedral virus spray. USDA Agric. Res. Serv. and For. Serv., Portland, Oreg. Unpubl.

A four-part report on the cooperative tests in 1965 by the Agricultural Research Service and the Forest Service to develop operational procedures for application of water-based polyhedrosis virus sprays in Douglas-fir tussock moth control. Each part is abstracted separately and filed under the author. For abstracts, see the following authors: C. W. Getzendaner; C. G. Thompson; K. H. Wright and R. R. Mason; and V. D. Young.
Control - 6, 9

291. U.S. Department of Agriculture, Forest Service. 1966. Prospectus for a joint research administrative effort to develop and test a method for using a nuclear polyhedrosis virus against the Douglas-fir tussock moth. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. and Reg. 6, Portland, Oreg. 9 p. Unpubl.

The present prospectus is an expansion of a previous outline of steps for operational testing of the nuclear polyhedrosis virus into a proposal indicating the scope of the undertaking and estimating the funds, manpower, facilities, and time needed to carry out the project. "The proposal calls for combining regular research, survey, and control efforts and supplementing them with funds to speed operational testing of the nuclear polyhedrosis virus as a control agent." The test will be

conducted in 1967, or "as soon thereafter as a suitable area becomes available."
Control - 6

292. U.S. Department of Agriculture, Forest Service. 1971. Douglas-fir tussock moth in California forests 1970-1971. Calif. Reg. Pam.

A Douglas-fir tussock moth epidemic was reported in several locations in California in 1970. This publication discusses the history of past outbreaks, ecological factors leading to outbreaks, the life cycle and damage, and possible control methods.
General Background

293. U.S. Department of Agriculture, Forest Service. 1972. Results of field experiments for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus, and associated studies. USDA For. Serv., Prog. Rep. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. Unpubl.

This is a six-part report on the 1971 field test of nuclear polyhedrosis virus spray application for control of the Douglas-fir tussock moth. A stand of white fir in the Eldorado National Forest, California, served as the test site. Each report is abstracted separately. For abstracts see the following authors: D. L. Dahlston and R. F. Luck; B. Maksymiuk; M. E. Martignoni; R. R. Mason; R. D. Orchard; M. J. Stelzer; R. A. Waite; and B. E. Wickman.
Control - 6, 9

294. U.S. Department of Agriculture, Forest Service. 1973. Environmental statement, Douglas-fir tussock moth pest management plan, Oregon and Washington - 1973. USDA For. Serv. Pac. Northwest Reg., Portland, Oreg. 205 p. Unpubl.

"The USDA Forest Service proposed a pest management program for integrating natural biological control agents, silvicultural practices, and chemicals to minimize forest resource losses, particularly timber and

recreational values. This objective will be accomplished by: (1) harvest cutting of affected areas of commercial-size timber where serious tree damage has been and is expected to occur and where economic, environmental, and other factors warrant; (2) chemically treating affected high-use, high value recreational areas with Zectran on an operational test basis; (3) and reforestation of all affected areas where necessary." The proposed Zectran treatment will be at a dosage of 0.15 lb/acre in two aerial applications.

"The environmental impact of the proposed action and the alternatives are considered and evaluated." Plans for environmental monitoring are presented.

The appendices include an entomological evaluation of the pest population status in Oregon and Washington in 1972-73 and comments received on the tussock moth outbreak and possible control from interested persons and agencies.
Control - 1

295. U.S. Department of Agriculture, Forest Service. 1973. USDA-USDI Environmental Statement. Cooperative Douglas-fir tussock moth management plan. Idaho-Oregon-Washington. USDA For. Serv., Pac. Northwest Reg., Portland, Oreg. 301 p. Unpubl.

The USDA Forest Service proposed to treat chemically an estimated 650,000 acres of Douglas-fir tussock moth-infested forest land in Oregon, Washington, and Idaho in the spring of 1974. The environmental impact of the proposed DDT treatment is evaluated.

The statement covers: the appraisal of the forest situation, the biology of the Douglas-fir tussock moth, the history of destructive epidemics, proposed DDT control plan, the environmental monitoring plan, the impact on the environment of DDT application, the unavoidable adverse effects of DDT, the benefits of DDT use, the alternatives to control with DDT, and public response to the proposed DDT control project.

The appendices include: the entomological evaluation of the pest status in Oregon, Washington, and Idaho in 1973, the cost-benefit analysis, and the Pest Action Council's Resolution and problem analysis on the Douglas-fir tussock moth outbreak.
Control - 2, 3

296. U.S. Department of Agriculture, Forest Service. 1974. Douglas-fir tussock moth project - 1974. Oregon-Washington-Idaho. USDA For. Serv. Insect and Dis. Control, Reg. 6, Portland, Oreg. 18 p. Unpubl.

This report on the Douglas-fir Tussock Moth Control Program was submitted to the Environmental Protection Agency as required by the February 28, 1974, Order authorizing the emergency use of DDT for tussock moth control.

The location, quantity, times, and places of aerial application are included. A treatment summary for each Project Unit showing the date treated, the number of gallons applied, and the acres treated by numbered spray blocks is also included. A summary of the Dylox and Sevin-4-oil treatments is given. Accounts of insecticide accidents that occurred during the operation are included.
Control - 1, 2

297. U.S. Department of Agriculture, Forest Service. 1974. Environmental Analysis. Douglas-fir tussock moth, microbial insecticide pilot tests. USDA For. Serv. North. Reg., Missoula, Mont. 31 p. Unpubl.

The USDA Forest Service proposes to pilot test two biological control agents, Bacillus thuringiensis and a nucleopolyhedrosis virus, on the Douglas-fir tussock moth outbreak in northern Idaho, to obtain data leading to the possible registration of one or both. A pilot test is proposed on 17,500 acres. The tussock moth is predicted to cause defoliation on 104,000 acres in 1974.

The report examines the impact of the Douglas-fir tussock moth on timber stands if left uncontrolled, the favorable and unfavorable environmental effects of control with virus or B.t., and the alternative control measures available.

Appended is a work plan for pilot tests, a history of pest epidemics and suppression activities, an entomological evaluation of the epidemic, and background information on the microbial agents.
Control - 5, 6

298. U.S. Department of Agriculture, Forest Service. 1974. Project plans for the 1974 tussock moth control project. USDA For. Serv., Pac. Northwest Reg., Insect and Dis. Control Branch, Portland, Oreg. 106 p. Unpubl.

This report gives detailed plans for a proposed control project against the Douglas-fir tussock moth in 1974. The area will be sprayed with 3/4 lb of DDT in 1 gal of No. 2 fuel oil and auxiliary hydrocarbon solvent per acre. About 376,000 acres will be sprayed in Oregon and Washington. Application will be made from helicopters flying in tandem with an observation helicoper supervising. Areas will be released for control according to the results of natural virus and egg viability tests completed in March 1974. The report details the organization and duties of project personnel; the project procedures; the communications, meteorological, and environmental monitoring plans; and the safety plans for all phases of the project. General provisions in contracts for insecticide mixing and spraying are presented.

The sampling procedure and data analysis to measure population survival, assess foliage saved, measure the number of egg masses in the fall after treatment, and determine the success of treatment in preventing top-kill and tree mortality is outlined. Appended are lists of terminology used, tagging techniques, a sample of all forms used for recording data, sample organization charts, monitoring procedures for residues in the environment, and emergency phone numbers.
Control - 2

299. U.S. Department of Agriculture, Forest Service. 1974. Situation statement, Douglas-fir tussock moth, Oregon-Washington-Idaho. May 23, 1974. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. 8 p. Unpubl.

An analysis of the tussock moth outbreak in the Northwest is presented. Subjects considered are the host life cycle, biological evaluation, environmental statements, the role of the DFTM Interagency Steering Committee, treatment plans for 1974, and research currently being done on control of the tussock moth.
Outbreaks - 2; Control - 2; Related Material - 2

300. U.S. Department of Agriculture, Forest Service. 1974. Proceedings. Workshop -- Aerial application of insecticides against forest defoliators (chemicals and microbials). Univ. Mont., Missoula. April 23-25, 1974. USDA For. Serv., State and Private Forestry, North. Reg., Missoula, Mont. 128 p.

A series of discussions is presented on the problem of improving aerial spray technology to provide effective aerial application of insecticides against forest defoliators. It includes discussions on mixing and formulation of chemicals, selection of aircraft, meteorological prediction models for spray-deposit assessments, sampling and monitoring techniques, and safety and disposal systems for toxic chemicals.

Articles by W. E. Bousfield; P. R. Canutt; R. K. Dumbauld, H. E. Cramer, and J. W. Barry; P. A. Grau; and P. J. Iwai and M. E. Martignoni are abstracted separately.
Control - 7

301. U.S. Department of Agriculture, Forest Service. 1974. USDA Environmental statement. Cooperative Douglas-fir tussock moth pest management plan. USDA For. Serv., Pac. Northwest Reg., Portland, Oreg. 335 p. Unpubl.

In accordance with the requirements of the EPA, the USDA Forest Service prepared a statement on the environmental impact of the proposed treatment with DDT of the Douglas-fir tussock moth outbreak in Washington, Oregon, and Idaho. The statement covers all affected lands to be treated regardless of ownership.

The statement covers: the appraisal of the forest situation, the biology of the Douglas-fir tussock moth, the history of destructive epidemics, the proposed DDT control plan, the environmental monitoring plan, the impact on the environment of DDT application, the unavoidable adverse effects of DDT, the benefits of DDT use, the alternatives to control with DDT, the public response to the proposed DDT control project, and the supporting research and development programs for a Douglas-fir tussock moth pest management plan.
Control - 2, 3

302. U.S. Department of Agriculture, Forest Service. [n.d.] Saving the forests. Burns project, tussock moth control. USDA For. Serv., Malheur, Ochoco Natl. For. 4 p. Unpubl.

A popular account is given of plans for a forest pest control spray project in the Malheur and Ochoco National Forests, against the Douglas-fir tussock moth. Histories of past outbreaks and the present one are briefly examined. The present and potential economic loss from defoliation, the acres to be sprayed, the groups approving the control project, and the surveillance efforts to be carried out for possible effects of the spray on other resources are reviewed.
Control - 2

303. U.S. Department of Agriculture, Forest Service and Cooperators. 1974. Interim report. Douglas-fir tussock moth research and pilot test program season of 1974. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. 24 p. Unpubl.

After a concise examination of the history and status of the current Douglas-fir tussock moth outbreak in Oregon, Washington, and Idaho (Blue Mountains), 1972-1974, this report concentrates on a summary of the about 30 studies initiated in 1974 on the population dynamics of the moth and its control. Fourteen of these studies are summarized separately in the Appendix

Findings of particular significance at this point in the research program are: for a given locality, the present outbreak conformed to the 3-year cycle; tree mortality was related to the percentage of Douglas-fir in the infested stand; tests of microbial insecticides, nucleopolyhedrosis virus, and *Bacillus thuringiensis* showed promise for control; pilot tests of Sevin-4-oil at 2 lb/acre gave effective control, and Dylox also appeared promising but more testing is needed. DDT was more effective against the tussock moth than any other material tested, and a reduced dosage of 1/2 lb/acre was as effective as the standard 3/4 lb/acre. Small-scale aerial tests of Orthene gave promising results for further testing; in ground-application screening tests of 14 new insecticides, five gave over 90% control, with two compounds, Phosvel® and FMC-33297, reducing population levels by 99%; the natural sex attractant of the tussock moth has been identified, synthesized, and field tested with excellent results as a field sampling technique.
Biology - 2; Outbreaks - 4; Control - 1, 2, 5, 6; Related Material - 2

304. U.S. Department of Agriculture, Forest Service, and Cooperative State Research Service. 1976. The tussock moth program. USDA For. Serv. and Coop. State Res. Serv. Pam.

"The USDA Expanded Douglas-fir Tussock Moth Research and Development Program is a 3-year effort (1975-1977) designed to solve problems caused by periodic outbreaks of the Douglas-fir tussock moth in western conifer forests. Major goals of the program are to: (1) implement methods that are presently available to reduce damage caused by the tussock moth outbreaks, and (2) develop the new knowledge necessary to prevent or suppress future outbreaks." This pamphlet discusses the need for new control methods, the past status of the tussock moth, the expected

accomplishments of the program, and the means by which the objectives will be accomplished.
Related Material - 2

305. U.S. Department of Agriculture, Forest Service and Cooperative State Research Service. 1976. Tussock moth program progress report. USDA For. Serv. and Coop. State Res. Serv. Pam.

This pamphlet discusses the purpose and background of the Douglas-fir tussock moth program and reports on the progress made in each of its five main phases. Researchers have learned that the natural sex pheromone of the moth can be used to detect low-level populations. They have developed techniques for sampling low-level populations, explored the predator-parasite complex attacking the moth, studied the relation of outbreaks to forest conditions, tested chemical alternatives to DDT, experimented with microbial insecticides, and developed improved methods of aerial application of insecticides.
Related Material - 2

306. U.S. Department of Agriculture, Forest Service and Cooperative State Research Service. 1977. Tussock moth program progress report. USDA For. Serv. and Coop. State Res. Serv. Pam.

This pamphlet discusses the purpose and background of the Douglas-fir Tussock Moth Program and reports on the progress made in each of the five main phases of the program. The sex attractant of the tussock moth is being used to provide better survey techniques and thus a better understanding of population dynamics. Site factors are being analyzed to elucidate the relation of outbreaks to forest conditions. Chemical and microbial insecticides are being tested to develop new methods of suppression and regulation. A conceptual economic model has been developed to determine the socioeconomic impact of the tussock moth. A pest-management system will result from a synthesis of the first four phases.
Related Material - 2

307. Van Dyke, W. 1974. The Douglas-fir tussock moth. The situation as of January 1974. OSPIRG Reports. 40 p. Unpubl.

The paper reports the research undertaken by OSPIRG to determine the necessity of the USDA Forest Service request for use of DDT to control the Blue Mountain outbreak in 1973 and 1974. OSPIRG concludes that DDT would not have prevented a large proportion of the damage that occurred in 1973 because more than half of the severe damage was in areas where it was not anticipated by the Forest Service surveys and thus not included in the proposed spray areas. It charges that tests of alternative chemical insecticides were poorly handled and the results equivocal. OSPIRG contends that the Forest Service has not established either that DDT is the most effective control against the Douglas-fir tussock moth or that the Blue Mountain infestation warrants control by DDT based on accurate assessments of population trends.

OSPIRG recommends that: areas already severely damaged should not be considered for control; a new population survey and a revised estimate of potential damage is needed; areas for spray treatment should be chosen on the basis of data demonstrating significant potential damage; the EPA should require verification of the efficacy of DDT against the moth; and the Forest Service should demonstrate that gains from DDT use offset potential hazards.
Control - 4

308. Volck, W. H. 1907. The California tussock moth. Univ. Calif., Coll. Agric. Bull. 183:191-215. Agric. Exp. Stn., Berkeley, Calif.

Preliminary studies of a tussock moth affecting apple trees in California are presented. Although the moth was not identified, its life history and the feeding habits of the larvae are well described. Young larvae feed on both the foliage and the newly formed fruit. Older larvae are strictly foliage feeders. Rearing of collected larvae and pupae yielded a number of parasites including a tachinid fly, several species of ichneumonid wasps, other parasitic wasps and a chalcid wasp. Eggs are

attacked by a hymenopteran (Telenomus orgyia Ash.) and the larvae of a dermestid beetle. Disease was scarce.

Control by chemicals is difficult because the larvae are relatively resistant to arsenic compounds. First-instar larvae are the most susceptible. Contact poisons were ineffective. The only reliable control is hand removal of the overwintered egg masses. If the larvae emerge before egg mass removal, a secondary control measure is beating the trees to force the larvae to fall and attaching a sticky band to the tree trunk to prevent reascent of the larvae.
Related Material - 3

309. Waite, R. A. 1977. Spread factors of pesticidal spray formulations on Kromekote cards. USDA For. Serv. Res. Note PNW-286, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"To determine spherical drop size from a known spot size on a particular sampling surface it is necessary to know the spread factor for droplets of pesticide formulations." Preparations of the Douglas-fir tussock moth nucleopolyhedrosis virus, NPV, were among the formulations tested.
Control - 7, 8, 9

310. Washburn, R. I., and W. E. Cole. 1960. The use of virus to control tussock moth. USDA For. Serv. Prog. Rep., 11 p. Intermt. For. and Range Exp. Stn., Ogden, Utah. Unpubl.

This study attempted to determine susceptibility of various tussock moths to the Douglas-fir tussock moth virus, approximate dosage required for establishment, and expected mortality curve from the various dosages tested. In addition, it was intended to develop practical means of propagating the virus so that an adequate supply would be available for field tests.

"Supplies of virus can be maintained or increased in the laboratory by spraying immature tussock moth larvae with a virus solution at the rate of 1 million polyhedra per ml, 1/12 ml per cage; optimum virus concentration tested was 10 million polyhedra per ml, 1/12 ml per cage. Infected immature larvae yielded approximately 50 million and mature larvae yielded about 300 million polyhedra per individual.

"The virus was established when applied at the rate of 10 million polyhedra per acre against a tussock moth infestation on bitterbrush. Excellent control can be obtained the same year with an application of 50 million polyhedra per acre."

This work showed that tussock moths infesting bitterbrush in Nevada, white fir in New Mexico, and Douglas-fir in southern Idaho were susceptible to the virus stock.
Control - 6

311. Watt, K. E. F. 1968. A computer approach to analysis of data on weather, population fluctuations, and disease. _In_ Biometeorology, p. 145-159. W. P. Lowry, ed. Proc. 28th Ann. Biol. Colloq., 1967. Oreg. State Univ. Press, Corvallis.

Using historical records from interior British Columbia, a correlation was found between mean monthly temperature during July and August and numbers of the Douglas-fir tussock moth.
Biology - 1

312. Wear, J. F., and W. J. Buckhorn. 1955. Organization and conduct of forest insect aerial surveys in Oregon and Washington. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. 41 p. Unpubl.

This report describes the organization and conduct of annual forest insect aerial reconnaissance surveys of the 49,000,000 acres of forested lands in Oregon and Washington as now practiced by the Division of Forest Insect Research of the Pacific Northwest Forest and Range Experiment

Station and its cooperators. Surveys for the Douglas-fir tussock moth are conducted from July 1 to September 1.
Outbreaks - 2

313. Webb, W. L., and J. J. Karchesy. 1977. Starch content of Douglas-fir defoliated by the tussock moth. Can. J. For. Res. 7(1):186-188.

"Defoliation by the Douglas-fir tussock moth (Orgyia pseudotsugata (McDunnough)) resulted in a reduction of total tree reserve energy in the form of starch, proportional to the intensity of defoliation. This reduction was significantly less on a site with faster growing trees."
Outbreaks - 5

314. Webb, W. L., and K. Kilpatrick. 1976. Defoliation of Douglas-fir in a tussock moth outbreak near Kamloops, B.C. In Proc. Symp. Terr. Aquat. Ecol. Stud. Northwest, March 26-27, p. 135-143. East. Wash. State Coll., Chaney.

"Refoliation of trees defoliated by the Douglas-fir tussock moth is likely related to bud incidence and available tree reserve energy. In this paper, we present data on the variation in bud incidence and variation in starch content for both defoliated and undefoliated Douglas-fir. Some of the data show a decline in bud incidence with increased defoliation, and show also a linear decline in foliar starch with increased defoliation."
Outbreaks - 5

315. Weeds Trees and Turf. 1975. Aerial war on two fronts: tussock and gypsy moths. Weeds Trees and Turf 14(3):16-17, 28, 30.

A popular account is given of the control projects on the tussock and gypsy moth outbreaks. DDT was used effectively on the tussock moth outbreak in Washington, Oregon, and Idaho and Dylox was used on the gypsy moth, on small, widely scattered tracts in Pennsylvania.
Control - 2

316. Wellenstein, Von G., and K. Fabritius. 1973. Beobachtungen am Schlehenspinner (*Orgyia antiqua* L.) und seinen Parasiten. (Observations of *Orgyia antiqua* L. and its parasites) Anz. Schaedlingskd. Pflanzenschutz 46(2):24-30. [In Ger.]

The first appearance in large numbers of *Orgyia antiqua* in the spruce forest of southern Germany gave the opportunity of observing this insect pest and its parasitoids under field and laboratory conditions. In warm regions and years, this insect has 2 generations a year.

The older larvae bear poison hairs. Extended handling of the cocoon cause severe irritation (urticaria).

The outbreak of *Orgyia antiqua* in middle-European forests occurs in intervals from 50 to 60 years, with no preference for any one area. High populations in the same stand for several years are seldom encountered. A loss of increment results from a high population density. The outbreaks generally occur in the center of closed forests.

In the study area (about 7 km north of Bad Wurzbach, Baden-Wurttemberg), the authors found 48.4% females in the second generation, and a pupal mortality of 4.4%. The number of eggs laid was higher in the center than in the peripheral zones of the infestation.

The most important parasitoids were *Coccygomimus turionellae* (L.) (pupae), *Phobocampe crassiuscula* (Grav.) (larvae), and *Telenomus dalmanni* (Ratz.) (eggs). The density of the population of these parasitoids has been studied in heavily infested as well as in lightly populated areas.

The systematics, host species, life cycle, sexual index, and the behavior of the parasitoid *Telenomus dalmanni* are described.
Related Material - 3

317. Wernz, J., and G. P. Markin. 1977. Flow rates and characteristics of Dimilin, Dylox 1.5, Orthene 75S, and Sevin 4-oil. USDA For. Serv.,

Res. Note PNW-300, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Tests of aerial application of insecticides for Douglas-fir tussock moth control require knowledge of the flow rate of each chemical through the spray nozzle. Standardized equipment was used to evaluate the flow rates for Dimilin, Dylox 1.5, Orthene 75S, and Sevin 4-oil at five pressures and four temperatures with three standard T-jet nozzles. "Physical properties of settling, density, and viscosity and handling characteristics are also discussed."
Control - 7

318. Wert, S. L., and B. E. Wickman. 1968. White fir stands killed by tussock moth . . . 70 mm color photography aids detection. USDA For. Serv. Res. Note PSW-168, 5 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

An aerial survey technique to determine the extent and severity of white fir damage after defoliation by the Douglas-fir tussock moth is described. Large-scale, 70-mm aerial photography was used to increase detection accuracy and allow for stereoscopic viewing of the film in an uncut roll. Aerial photographs were taken of three separate sites at the tussock moth infestation in the Modoc National Forest, California. Comparisons were made between field assessments of tree crown conditions and interpretations from aerial photographs of selected 0.2-acre plots within the test sites. Interpreters of the aerial photographs were able to detect dead white fir trees with a high degree of accuracy but were less able to distinguish the degree of top-kill or thin foliage compared with ground estimates of the same trees. With more training, the interpreters could more accurately detect top-kill and thin foliage crowns.
Host Relationships - 1; Outbreaks - 5

319. Wert, S. L., and B. E. Wickman. 1970. Impact of Douglas-fir tussock moth . . . color aerial photography evaluates mortality. USDA For.

Serv. Res. Pap. PSW-60, 6 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Large-scale, 70-mm aerial photography was tested as a method of measuring white fir mortality and crown conditions after defoliation by the Douglas-fir tussock moth in the Warner Mountains, California. The surveys took place 3 years after a serious outbreak of the moth. In addition, the use of small-scale (1:8,000), 9-by-9 inch format, color aerial photographs to map and stratify insect damage was examined.

Ground surveys of the areas to be photographed were made both as a check against the photographs and to provide sample data for estimating total white fir damage in the area. "Comparisons of the photo interpretations with a sample ground cruise gave high correlations (0.78 to 0.95) for tree mortality and top-kill, and an estimate of mortality made from photos was within 5% of the ground cruise estimate."
Host Relationships - 1; Outbreaks - 5

320. Wickman, B. E. 1958. Mortality of white fir following defoliation by the Douglas-fir tussock moth in California, 1957. USDA For. Serv. Calif. For. and Range Exp. Stn. Res. Note 137, 4 p. Berkeley, Calif.

The 1954-56 Douglas-fir tussock moth infestation of white fir in the Stanislaus National Forest covered seven scattered blocks and 10,000 acres. A study conducted in 1957 of tree mortality on selected plots in the infestation sites showed 21% of the trees were killed on heavily defoliated plots. One-fourth of the mortality was caused by defoliation alone, the other defoliated trees were killed by bark beetles. Only trees 50-100% defoliated were killed. Damage to trees less than 50% defoliated resulted in reduced growth.

The plots will be checked annually in August until 1960.
Host Relationships - 1; Outbreaks - 5

321. Wickman, B. E. 1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PSW-7, 15 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

"Damage caused by the Douglas-fir tussock moth was studied in white fir stands in California. The data collected were from the Stanislaus infestation of 1954-56 and the Inyo infestation of 1934-38. Mortality of white fir was caused by defoliation alone and by a combination of defoliation and attacks by cambium-mining beetles. More small trees were killed than large ones. In the most heavily defoliated stands, 20% of the saw-timber volume (11,071 fbm per acre) died in the 5 years immediately after the end of the Stanislaus outbreak. Twenty-nine % of the volume (10,595 fbm per acre) was killed in the 5 years after the Inyo outbreak.

"Top damage in the Stanislaus infestation was most severe in the heavily defoliated trees; 12% of them being top-killed as a result of tussock moth feeding. Many small trees suffered temporary top dieback, but later grew new leaders. Loss of radial growth was pronounced and similar for both infestations. The loss was most noticeable in trees more than 30% defoliated. Defoliation had an immediate effect upon white fir growth, and when feeding stopped, growth increased immediately. Differences in growth between top, midcrown, and base were noticeable before and after defoliation. In almost every case the base was growing more slowly and the magnitude of loss was proportionately greater in the upper crown."

Growth losses of merchantable white fir combined with mortality totaled 12,184 fbm per acre, or more than one-fifth of the original stand volume.
Host Relationships - 1; Outbreaks - 5

322. Wickman, B. E. 1972. Preliminary report on the effects of Douglas-fir tussock moth larval populations on defoliation of white fir. Part V. In Results of field experiments for controlling Douglas-fir

tussock moth with aerial application of polyhedrosis virus and associated studies. Progress Report. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg. 9 p. Unpubl.

"Estimates of white fir defoliation by tussock moth larvae were made through the 1971 growing season on the Iron Mountain plots and on an undefoliated plot at Alder Ridge. Purposes of the measurements were to correlate defoliation with population levels. The major findings of this exploratory work are as follows. Sampling methods must be improved for estimating defoliation. There was no measurable difference in defoliation on the Iron Mountain treated and untreated plots, but there was a significant difference with a nearby nondefoliated plot. Larval populations in the 35 per 1,000 in^2 of foliage category cause significant foliage removal through one growing season. This relates to visual crown estimates which showed that 75% of the sample trees on the Iron Mountain plots suffered "light" defoliation. Quantitative data was obtained on white fir foliage production which will be valuable for future energy flow models of fir trees and their foliage consumers."
Outbreaks - 4, 5

323. Wickman, B. E. 1975. Research on population dynamics and impact in the Blue Mountains. West. For. Conserv. Assoc., Perm. Assoc. Proc. 1974:15. Portland, Oreg.

A brief synopsis of the tussock moth research underway at the Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, is presented. The population dynamics of the Douglas-fir tussock moth have been studied in depth at the extensive outbreak in the Blue Mountains to determine the nature of population change, natural mortality factors, and tree damage under natural conditions.
Outbreaks - 4

324. Wickman, B. E. 1976. Douglas-fir tussock moth egg hatch and larval development in relation to phenology of grand fir and Douglas-fir in northeastern Oregon. USDA For. Serv. Res. Pap. PNW-206, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Bud burst, shoot elongation, egg hatch, and larval development were studied on six areas in a 1973 infestation in the Blue Mountains." The study sites were located at various elevations in both pure stands of grand fir and Douglas-fir and in mixed stands. "Bud development was similar for both tree species except on the lower elevation plot where Douglas-fir bud burst preceded grand fir by several days. . . ."

"Bud burst and egg hatch were found to be closely related to accumulated degree-days, and peak egg hatch occurred after all buds had burst and shoots were 50% or more elongated." First egg hatch occurred at 80-100% bud burst on grand fir and 70-97% bud burst on Douglas-fir. "Larval development closely followed shoot elongation. This synchrony of host and insect phenology provides an easily observable field event for monitoring Douglas-fir tussock moth development."
Biology - 1; Host Relationships - 2, 3

325. Wickman, B. E. 1976. Phenology of white fir and Douglas-fir tussock moth egg hatch and larval development in California. Environ. Entomol. 5(2):316-322.

"The phenology of bud burst and shoot elongation of the host tree and egg hatch and larval development were studied on three areas in a 1972 infestation. Bud burst and egg hatch (of the Douglas-fir tussock moth) were found to be closely related to accumulated degree-days, and peak egg hatch occurred when 77-97% of the buds had burst." Complete dispersal of the larvae from the egg masses and extensive feeding occurred after 100% of the buds had burst. "Larval development then closely followed shoot elongation."
Biology - 1; Host Relationships - 1

326. Wickman, B. E. 1977. Douglas-fir tussock moth egg hatch and larval development in relation to phenology of white fir in southern Oregon. USDA For. Serv. Res. Note PNW-295, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The relation between bud burst and shoot elongation in white fir and egg hatch and larval development in the Douglas-fir tussock moth was studied in two areas near Fort Klamath, Oregon. "The study areas had low populations of the Douglas-fir tussock moth. Bud burst was found to be closely related to accumulated degree-days, and peak egg hatch occurred after all buds had burst and shoots were 40% elongated. Larval development then closely followed shoot elongation." The phenological relations for tussock moth egg hatch and larval development on white fir in California and on grand fir and Douglas-fir in northeastern Oregon are similar to those indicated by this study.
Biology - 1; Host Relationships - 1

327. Wickman, B. E. 1977. Observations on spider predation of early instar larvae of Douglas-fir tussock moth, Orgyia pseudotsugata (McDunnough) (Lepidoptera: Lymantriidae). Pan-Pac. Entomol. 53:46.

On one occasion a medium-sized spider (about 6-8 mm long) removed and apparently stung two newly hatched Douglas-fir tussock moth larvae. On two other occasions, medium-sized spiders (5-8 mm) were seen opening tussock moth eggs and eating the larvae that were ready to emerge.
Biology - 3

328. Wickman, B. E., R. R. Mason, and H. G. Paul. 1975. Flight, attraction, and mating behavior of the Douglas-fir tussock moth in Oregon. Environ. Entomol. 4(3):405-408.

"Continuous observations and measurements were made of adult flight, mating, and oviposition of Orgyia pseudotsugata McDunnough over a 31-h period in eastern Oregon. Male flight started at 1,000 (P.S.T.), gradually increased to a peak period at ca. 1700, and concluded at 1930. This coincided with peak mating activity with the wingless females. Oviposition occurred immediately after mating." Females were observed mating more than once, on several occasions after ovipositing most of their eggs. Some females oviposited without mating. "Virgin females attached to sticky traps were very effective for attracting and capturing

male moths. The female sex pheromone offers a possible technique for early detection of Douglas-fir tussock moth populations."
Biology - 1, 2

329. Wickman, B. E., R. R. Mason, and C. G. Thompson. 1973. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. USDA For. Serv. Gen. Tech. Rep. PNW-5, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Case histories of five tussock moth outbreaks that occurred in California and Oregon between 1935 and 1965 are discussed. Information is given on the size and duration of the outbreaks, the presence of natural control agents and the damage caused. Most of the outbreaks were eventually treated with DDT. However, enough information was available from untreated portions to show the probable trend of natural events in the absence of direct control. Repeated patterns observed in each of the outbreaks enabled certain generalizations to be made about natural population behavior and tree impact.

"All infestations followed a 3-year cycle with inconspicuous to minimal defoliation the first year, severe foliage loss the second year, and ultimate collapse of the population by the end of the third year. The most severe tree damage occurred in the second year. Additional loss of foliage before population collapse in the third year was usually of minor importance in terms of total impact. Although other natural factors were involved, a virus disease appeared to be the principal cause of insect mortality during collapse."
Outbreaks - 1

330. Wickman, B. E., and D. A. Renton. 1975. Evaluating damage caused to a campground by Douglas-fir tussock moth. USDA For. Serv. Res. Note PNW-257, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The impact of Douglas-fir tussock moth defoliation on recreational values was studied at the Stowe Reservoir campground, Modoc National Forest. Tree mortality and top-kill of white fir were tallied and evaluated. "Cleanup costs for hazardous trees and dead tops amounted to $23.75 per camp unit. When esthetic values were assigned to trees, the insect damage costs increased to $126.88 per camp unit. Campground trees should be assigned some replacement value rather than their timber value to aid the pest management specialist in determining the level and kind of suppression technique to be applied against a given pest."
Host Relationships - 1; Outbreaks - 5

331. Wickman, B. E., and R. F. Sharpf. 1972. Decay in white fir top-killed by Douglas-fir tussock moth. USDA For. Serv. Res. Pap. PNW-133, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Stands heavily defoliated in 1936-37 by the Douglas-fir tussock moth, Hemerocampa pseudotsugata McD., at Mammoth Lake, California, were studied to determine the incidence and extent of decay in top-damaged trees. This was done by dissecting the tops of trees felled during logging. Comparisons were made with white fir in a nearby logged area that was not defoliated during the old outbreak. Few decay organisms were isolated from trees top-killed by Douglas-fir tussock moth. However, old top damage and a condition known as wetwood were common in the infested area. Wetwood was found in 17 of 21 top-damaged trees in the infested area and in one of 50 trees in the uninfested area. We conclude therefore, that in east-side Sierra Nevada white fir stands, the threat of defect is not economically serious in large trees that will be logged within 35-40 years after top-damage."
Host Relationships - 1; Outbreaks - 5

332. Wickman, B. E., G. C. Trostle, and P. E. Buffam. 1973. Douglas-fir tussock moth. USDA For. Serv. For. Pest Leafl. 86, 6 p. (Rev.)

This leaflet covers a brief history of the Douglas-fir tussock moth infestations; the outbreak cycle; a description of the damage of the

larvae; a description, life history and preferred hosts of the moth; and the alternatives of natural and chemical control.
General Background

333. Williams, C. B., Jr. 1974. Field test of four insecticides against the Douglas-fir tussock moth in Oregon. West. For. and Conserv. Assoc., Perm. Assoc. Comm. Proc. 1973:77-83. Portland, Oreg.

"In the spring and early summer in 1973, Federal and State resource agencies tested four insecticides on epidemic populations of the Douglas-fir tussock moth (Orgyia pseudotsugata) in the egg and early larval stages." Application was by helicopter. Insecticides and dosage rates applied were: Bioethanomethrin (BEM) at 0.01 lb/acre; carbaryl (Sevin) at 1 lb/acre; trichlorfon (Dylox) at 1 lb/acre; and mexacarbate (Zectran) at 0.15 lb/acre. Field dosages were determined from laboratory toxicity tests and dosages registered for similar species of defoliating moths. Zectran and Dylox were tested in single and double applications, BEM and Sevin by a single application.

Results of the tests were highly variable and inconsistent. Some of the variability in mortality resulted from increases in population densities during the tests, because spraying was done before all larvae had hatched. Poor or highly variable spray deposit and coverage further increased the variability of the population data.

Results of the test apparently do not provide sufficient information to evaluate the performance of the four materials against the Douglas-fir tussock moth. More field testing with different spray strategies is needed.
Control - 1

234. Wolf, K. 1975. Evaluation of the exposure of fish and wildlife to nuclear polyhedrosis and granulosis viruses. In Baculoviruses for insect pest control: Safety considerations, p. 109-111. M. D. Summers, R. Engler, L. A. Falcon, and P. V. Vail, eds. Am. Soc. Microbiol.

Suggestions for testing the impact of the Douglas-fir tussock moth polyhedrosis virus on nontarget organisms by the use of tissue cultures and in vivo experiments are presented. Attempts to replicate the virus in cell cultures of both fish and amphibians have given negative results.
Control - 6

335. Wright, K. H. 1975. An expanded research and development program for the Douglas-fir tussock moth -- 1975 to 1978. West. For. Conserv. Assoc., Perm. Assoc. Proc. 1974:24-30. Portland, Oreg.

An accelerated 3-year research program has been designed by the USDA, to detect, predict, and manage populations of the Douglas-fir tussock moth. From 1975 to 1978, members of the Forest Service and the Cooperative State Research Services will work to develop an integrated pest management system.

This paper summarizes the objectives, organization, and plans of the tussock moth cooperative research and development program.
Related Material - 2

336. Wright, K. H. 1977. The Douglas-fir tussock moth research and development program. Bull. Entomol. Soc. Am. 23(3):167-168.

The background of the creation of the Combined Forest Pest Research and Development Program and its organization and management are presented. Douglas-fir tussock moth program planning is briefly detailed and the five main phases of investigation are described. A short description of the Douglas-fir tussock moth and its status as a pest is included.
Related Material - 2

337. Wright, K. H., and R. R. Mason. 1966. Field tests at Mt. Hood, Oregon, to determine performance of water virus sprays. Part II. _In_ Results of tests to develop operational procedures for controlling Douglas-fir tussock moth with aerial application of polyhedral virus spray. USDA Agric. Res. Serv. and For. Serv., Portland, Oreg. 36 p. Unpubl.

"Helicopter tests were undertaken in June, 1965, on the Mt. Hood National Forest to further knowledge on how to apply water sprays of the type used for applying polyhedral virus of the Douglas-fir tussock moth. Specific objectives were to determine (1) the amount and distribution of water spray deposited under varying forest conditions when applied at the rate of 1 and 3 gal/acre, and (2) efficacy of using fluorescent tracer material for evaluating spray distribution."

The average dye spray recovery in tree crowns was 0.30 and 0.63 gal/acre, respectively, from trees sprayed at the rate of 1 and 3 gal/acre, and 0.14 and 0.60 gal/acre was recovered on the ground beneath the canopy. Coverage at the 3-gal rate was consistently more uniform. No significant difference occurred in the amount of dye spray recovered within trees from top, middle, and lower crowns. "Average deposits of fluorescent spray on sample cards at top, midcrown, and lower crown was 45, 30, and 25% respectively of the total deposited on the trees. Differences between top and other positions were statistically significant. This is in variance with findings from dye spray."

"In general, the fluorescent tracer material (Calcofluor white) worked well as a tagging material. Fluorescent materials are advantageous over dyes for ease of assessing spray coverage in the field. Droplets fluoresced brightly for 1 month after application."
Control - 9

338. Young, V. D. 1966. Development of equipment and methods for applying virus water sprays. Part I. In Results of tests to develop operational procedures for controlling Douglas-fir tussock moth with aerial application of polyhedrosis virus spray. USDA Agric. Res. Serv. and For. Serv., Portland, Oreg. 21 p. Unpubl.

The results of tests of equipment development and spray formulation are reported. Physical factors influencing droplet size are reviewed. A helicopter mounted with a 29-foot boom equipped with 37 nozzles was tested for effects of nozzle size, and type, and speed of application on deposit spectrum. Formulation tests centered on the discovery of a

sticker that would not affect colorimeter readings of a dye tracer incorporated into the solution. Corn syrup proved to be the most compatible. Appendices include the results of helicopter nozzle calibration tests, spray pattern data, and spray deposition cards. Control - 9

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physical consequences of large organic debris in pacific northwest streams

Frederick J. Swanson
George W. Lienkaemper

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture
Forest Service
Portland, Oregon

Abstract

Large organic debris in streams controls the distribution of aquatic habitats, the routing of sediment through stream systems, and the stability of streambed and banks. Management activities directly alter debris loading by addition or removal of material and indirectly by increasing the probability of debris torrents and removing standing streamside trees. We propose that by this combination of factors the character of small and intermediate-sized streams in steep forested terrain of the Pacific Northwest is being substantially altered by forest practices.

KEYWORDS: Sedimentation, stream environment, fish habitat, water quality.

This paper was originally presented in the Oregon State University "Logging Debris in Streams Workshop" in March 1977. This paper presents a broader conceptual framework and extends the data base presented in Swanson, et al. 1976. History, physical effects, and management implications of large organic debris in western Oregon streams. 15 p., illus. USDA For. Serv. Gen. Tech. Rep. PNW-56. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Authors

FREDERICK J. SWANSON is Research Associate, School of Forestry, Oregon State University, Corvallis. GEORGE W. LIENKAEMPER is Geologist at Forestry Sciences Laboratory, Corvallis.

Metric Equivalents

1 meter (m)	=	1.09 yard
1 cubic meter (m^3)	=	1.31 cubic yard
1 hectare (ha)	=	2.47 acre
1 square kilometer (km^2)	=	0.39 square mile
1 event/square kilometer	=	2.59 events/square mile

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Introduction

Large organic debris is such an important part of Northwest forest streams that consideration of stream debris really involves consideration of the entire aquatic ecosystem. The biological and physical characteristics of stream ecosystems in the Pacific Northwest have evolved over thousands of years in response to persistent, heavy loading of organic debris and periodic flushing events, variously termed sluice outs or debris torrents. Forest management activities may significantly alter levels of debris loading and the probability of flushing events. These alterations may have long-term impacts on the entire aquatic ecosystem. Before considering possible impacts of intentional or inadvertent debris management, it is worthwhile reviewing the physical characteristics, history, and effects of natural debris in streams of various sizes.

Physical Characteristics of Debris in Streams

The character of natural debris in Northwest streams was first documented by Froehlich and coworkers (Froehlich 1971, 1973; Froehlich et al. 1972; Lammel 1972) who called attention to and quantified the high natural levels of debris in Coast and Cascade Range streams. They also evaluated the impact of various timber falling and yarding systems on debris loading. Swanson et al. (1976) discussed large organic debris with regard to its history and physical effects. Here we briefly review relevant, published observations and emphasize several additional points concerning management impacts.

Physical characteristics of debris in streams vary systematically through stream systems. Debris loading

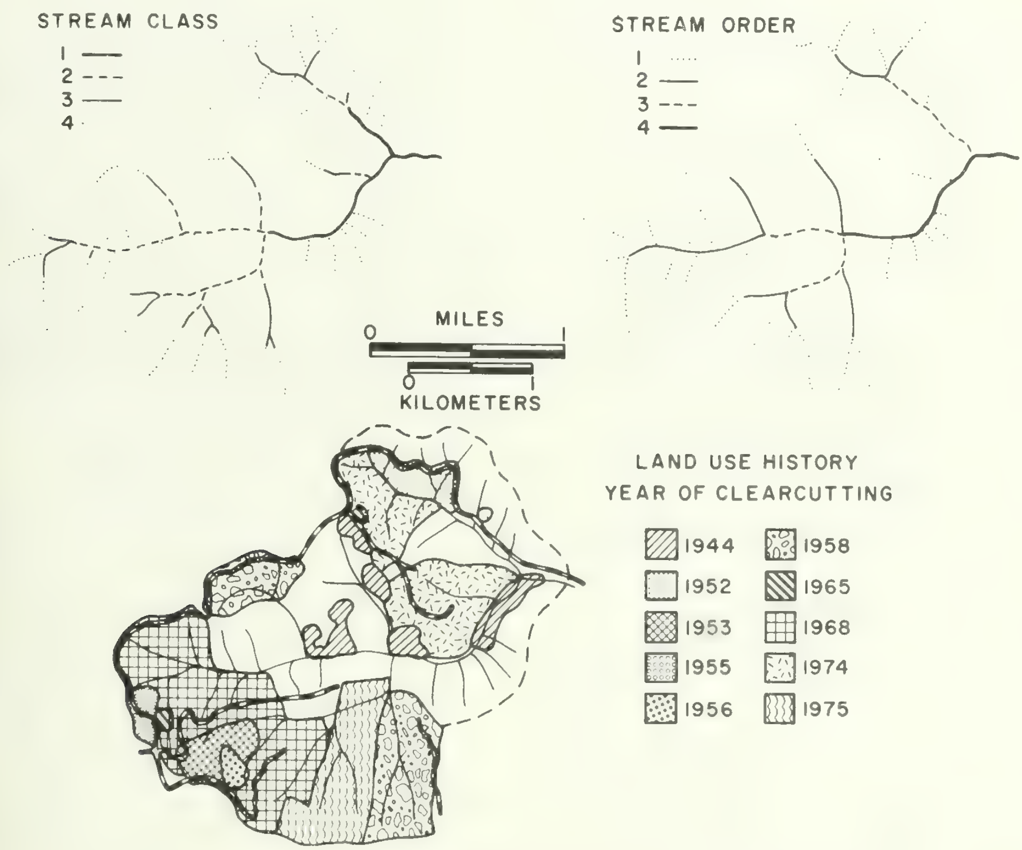

Figure 1.--Drainage network of Cedar Creek, Coast Ranges, in terms of U.S. Forest Service stream class, stream order, and history of timber harvest in the watershed.

is highest in small steep headwater streams and generally decreases downstream. In first- and second-order streams, large debris is randomly located where it inititally fell, because the streams are too small to redistribute it. (Stream order is defined in many geography texts and Harr (1976), and an example is shown in fig. 1). Third- through fifth-order streams are large enough to redistribute debris, forming distinct accumulations which may directly affect the entire channel width. In larger rivers, large debris is generally thrown up on islands or the banks and has little influence on the channel except at high flow conditions.

DEBRIS INPUTS TO STREAMS

Large organic debris enters streams by a variety of mechanisms, some of which are interrelated and act in chain reaction fashion. Principal mechanisms of debris input are blowdown of whole trees or tops and major limbs; debris slides, debris avalanches, and deep seated mass movements from adjacent hillslopes; undercutting of streambanks; and timber falling and yarding operations. Debris also enters stream sections from upstream channel reaches by flotation and debris torrent processes.

DEBRIS MOVEMENT IN STREAMS

Debris is moved through stream channels by flotation at high streamflows or in debris torrents involving rapid movement of a slurry of soil, alluvium, and large organic debris. Debris torrents typically originate in steep (> 50% slope) first- and second-order streams draining areas less than about 20 hectares (ha). Over 80% of 53 debris torrents studied in two areas in the Cascades were triggered by slides from adacent hillslopes (table 1). In these areas, mobilization of debris in channels was not a primary cause of debris torrents. In the steep, highly dissected terrain of the Oregon Coast Ranges, movement of shallow soil and organic debris in steep headwalls of incipient drainage ways commonly results in debris torrents. In these cases, it is difficult to determine (1) whether the initial mass movement should be considered a hillslope or channel event, and (2) if the presence of organic debris played a role in starting the debris torrent.

Table 1--*Land use status of triggering sites of debris torrents in the H. J. Andrews Experimental Forest (Swanston and Swanson 1976) and Alder Creek drainage (Morrison 1975, and pers. comm.)*

Site	Percent of watershed in 1975	Period of record (year)	Torrents triggered by hillslope slide	Torrent initiated in channel	Total number of torrents	Torrents per km^2 per year	Frequence of torrents relative to forest rate
H. J. Andrews Experimental Forest (6 420 ha)							
Forest	77.5	25	9	1	10	0.008	x 1
Clearcut	19.3	25	5	6	11	1/.036	x 4.5
Road right-of-way	3.2	25	17	--	17	1/.33	x 41
Total	100.0		31	7	38		
Alder Creek drainage (1 740 ha)							
Forest	70.5	90	5	1	6	.005	x 1
Clearcut	26.0	15	2	1	3	.004	x 8.8
Road right-of-way	3.5	15	6	--	6	1/.66	x130
Total	100.0		13	2	15		

1/ Event frequency is significantly different (P <0.01) from forest rate.

Flotation of large organic debris ay be a problem in intermediate-sized treams (third- to fifth-order, drainage reas of about 400 to 6 000 ha). These treams are wide enough to float large ebris during extreme flood flows. reexisting debris accumulations may e moved downstream for hundreds of eters, destroying riparian vegetation nd rearranging the channel along the ay. Several examples of such debris obilization in the H. J. Andrews xperimental Forest occurred where assive earthflows had constricted the hannel of Lookout Creek (Swanson and ames 1975). High streamflow resulted n numerous streamside slides and nput of abundant large organic debris o the stream. Much of this organic atter and sediment was then flushed ownstream 300 to 800 m before setting p in a massive jam. Such earthflow-nfluenced areas are sites of persistent treamside and channel instability.

Based on reconnaissance studies n the central Cascade and Coast Ranges n Oregon, debris torrents are very ommon events, particularly following learcutting and road construction. hese events transport large quantities f organic debris and sediment from mall streams into intermediate-sized treams. Massive debris export from he intermediate-sized streams occurs nder extreme flood conditions as afts and individual pieces of large ebris are floated downstream, damaging iparian vegetation along the channel. t present, there appears to be a eneral pattern of greatly increased ebris and sediment accumulation in any intermediate-sized streams. hese considerations are discussed urther in the section "Management mpacts on stream debris."

Although debris torrents are pectacular events of real management ignificance, they actually move aterial relatively short distances up to several kilometers). The ltimate export of large organic ebris occurs in the form of fine articulate and dissolved matter esulting from breakdown of wood by he action of decomposer organisms, nvertebrates, and snails. Organic atter in a log in a stream high in he mountains will eventually pass hrough many organisms' gut tracks in he course of transport down river to he sea.

CHANNEL MORPHOLOGY AND SEDIMENT ROUTING

Large debris in streams controls channel morphology and sediment and water routing. In streams to about third-order size, debris helps form a stepped gradient. The streambed is made up of long, low gradient sections separated by relatively short, steep falls or cascades. Therefore, much of the streambed may have a gradient less than the overall gradient of the valley bottom because much of the stream drop, or decrease in potential energy, takes place in the short, steep reaches. This pattern of energy dissipation in short stream reaches results in less available energy for erosion of bed and banks, more sediment storage in the channel, slower routing of organic detritus, and greater habitat diversity than in straight, even gradient channels.

One way to evaluate the role of debris in sediment routing is to compare the volume of sediment stored behind debris in a channel with annual sediment export from the channel. Megahan and Nowlin (1976) have observed, in several small forested watersheds in central Idaho, that annual sediment yield was only about 10 percent of sediment stored in the channel systems. Woody material made up 75 to 85 percent of the obstructions that trapped sediment. In the case of the 60-ha Watershed 2 in the H. J. Andrews Experimental Forest, average bedload export measured in a sediment basin has been 3.8 m^3 per yr for 1957-1976 (R. L. Fredriksen, pers. comm.). In a 100-m section above the basin, 20.1 m^3 of sediment is stored behind organic debris. The entire length of perennial and intermittent channel is about 1 700 m, so in this watershed annual sediment yield is probably much less than 10 percent of material in storage. Additional, unfilled storage capacity is available within the channel system.

The overall storage capacity serves to buffer the sedimentation impacts on downstream areas when there are pulses of sediment input to channels. Scattered debris in channels reduces the rate of downstream sediment movement and tends to feed sediment through the stream ecosystem in a slow trickle, except in cases of catastrophic flushing events. These flushing events may scour a channel every few centuries,

leaving the channel devoid of large organic debris and open to rapid transfer of bedload.

Debris also influences bank stability and the lateral mobility of channels. Debris-related bank stability problems in V-notch, bedrock-controlled streams result from undercutting of the soil mantle on hillslopes by debris torrents. Undercut slopes are subject to progressive failure by surface erosion and small scale ($< 100\text{-m}^3$) mass erosion events over a period of years. Both bank instability and lateral mobility can occur in channels with abundant alluvium and minimal bedrock influence. Changes in channel conditions and position may be greatly influenced by organic debris in the stream. A debris accumulation may cause a stream to by-pass the jam and cut a new channel. Where channels continue to flow through massive depositional areas, streamflow may be subsurface throughout much of the year. In areas of active creep and earthflows, lateral stream cutting may undermine banks and encourage further hillslope failure and accelerated sediment supply to the channel.

DEBRIS AND AQUATIC HABITAT

In small and intermediate-sized mountain streams in the Northwest, large organic debris may be the principal factor determining the characteristics of aquatic habitats. In other geographic areas where streams are characterized by "classic" meandering channel patterns, hydraulic factors are more important in regulating the distribution of aquatic habitats. The role of debris in creating habitat for fish has been reviewed by Narver (1971), Hall and Baker (1975), and others. In addition, the wood itself is a habitat or substrate for a great deal of biological activity by microbial, invertebrate, and other aquatic organisms (Sedell and Triska, 1977).

The influence of wood on aquatic habitats has been measured in several streams in the H. J. Andrews Experimental Forest. In a 245-m section of Mack Creek flowing through an old-growth stand, 11 percent of the stream area is in wood, 16 percent in wood-created habitat (primarily depositional sites) and 73 percent in non-wood habitat, mainly boulder dominated cascades. The studied section occ on a third-order channel where the stream drains about 600 ha. In Devilsclub Creek, a first-order tr tary draining 10 ha, wood comprise 25 percent of the stream area and another 21 percent is habitat infl by wood. Much of the biological activity by detritus-processing ar other consumer organisms is concer in the areas of wood and wood-rela habitat.

HISTORY OF DEBRIS IN STREAMS

The history of natural debris streams has been studied in two wa (1) by using dendrochronologic met to date the residence time of indi pieces of debris in streams and (2 examining the debris loading in st flowing through stands in differen stages of recovery following major wildfire. Debris in streams is da by ring counts on trees growing on down logs and on scars on living t damaged by debris falling into the stream.

Using these methods, we have commonly observed pieces of debris which have been in channels for 25 more than 100 years. Western redc is particularly longlasting, follo by Douglas-fir, western hemlock, and red alder in order of increasi rate of breakdown.

Debris loading has been studi in streams flowing through 75-, 85 90-, and 135-year-old stands. By evaluating debris size, residence in channel, and other factors, one determine whether the debris was derived from the pre-fire or post- stand. Some of these relationship are evident in figure 2, which sho debris in a stream section in a 75 year-old stand. The large diamete pieces were derived from the pre-f old-growth stand, and the small pi were input from the post-fire stan Observations in streams such as th indicate that the change in domina of debris of pre-fire and post-fir origin is gradual, occurring over than a century when the pre-fire s was old-growth (figure 3). Of cou the residence time of debris piece from the pre-fire stand depends on

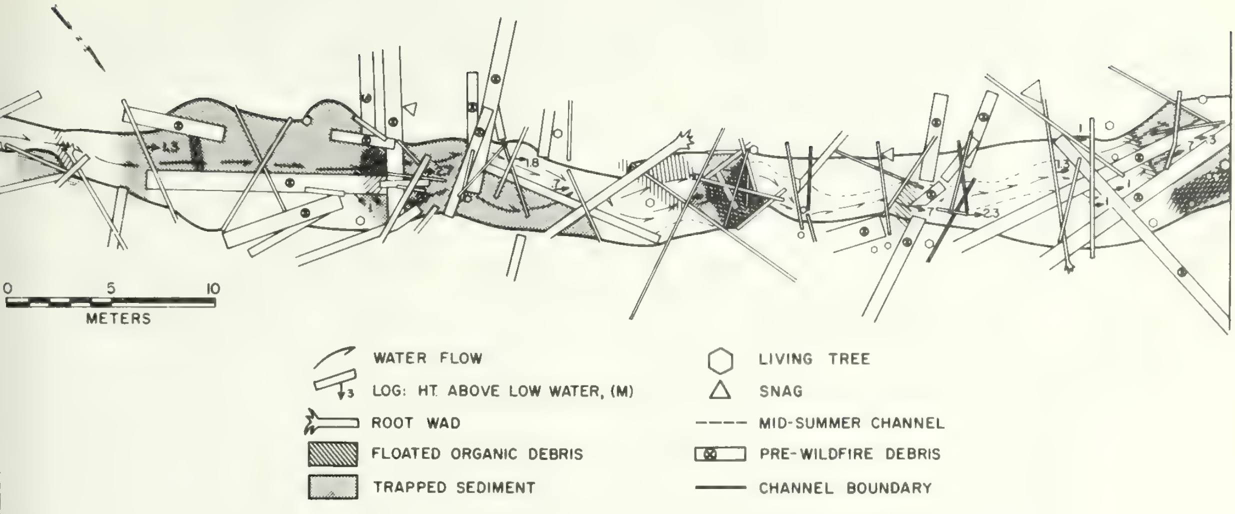

Figure 2.--Map of large organic debris in stream flowing through 75-year-old stand.

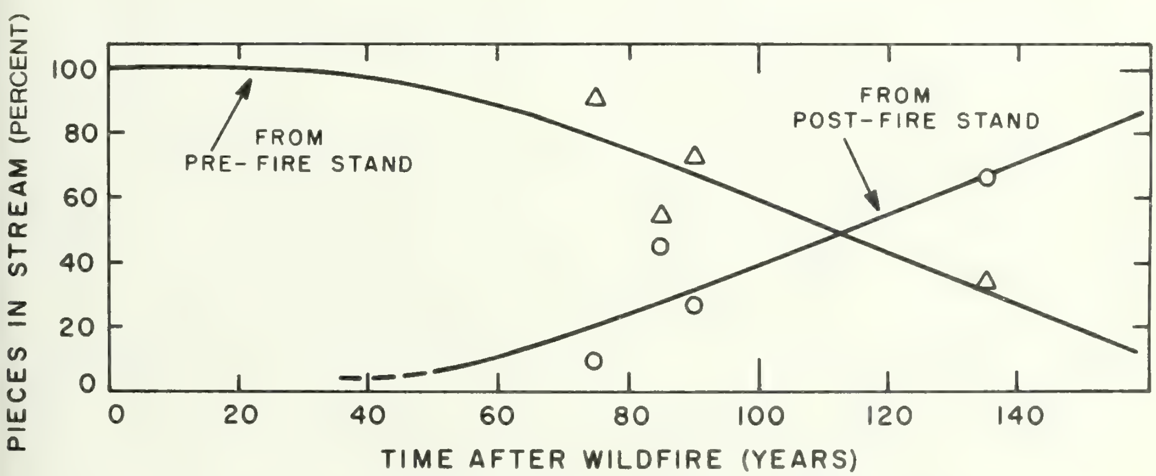

Figure 3.--History of stream debris loading in terms of change in percent of stream debris pieces derived from pre-fire (Δ) and post-fire (0) stands in relation to time after wildfire in three first-order streams in the Cascades.

ize distribution and species composi-ion. If the pre-fire stand was young hd the stream contained only small iameter material, the debris carried ver to post-fire conditions will ecompose faster than old-growth sized aterial. Under these circumstances, otal stream debris loading may decline ppreciably during stand reestablishment.

Total concentrations of organic debris from the 75-, 85-, 90-, and 135-year-old stands are about 50 percent of values for small streams flowing through old-growth stands (Froehlich 1973). Reduced loading in these second-growth stands is a result of the period of nonproduction of large debris during early stages of stand

development. The timing of large debris production varies greatly from stand to stand depending on stocking history and patterns of mortality. Carry over of debris from pre-fire stands is reduced by repeated fires within the period of several decades which may burn up old debris; and delayed establishment of the new stand while debris from the pre-fire stand continues to decompose.

In summary, we have observed that large organic debris in small and intermediate-sized streams may persist for long periods of time and through the period of stand reestablishment following wildfire.

MANAGEMENT IMPACTS ON STREAM DEBRIS

Management activities may have a great variety of impacts on stream debris. For any single action, it is difficult, if not impossible, to sort out near-term and long-term positive and negative impacts. This is in part true because any single action will be viewed differently by foresters, engineers, and stream biologists. The following general statements concerning management impacts may be made, however, based on the assumption that a management goal is to maintain concentrations and size distributions of debris typical of natural stream channels.

Increased debris loading in streams may result either from direct input during logging and road construction operations or by mass movement activity sometime after logging. Extremely high levels of debris loading result in abundant habitat for wood processing organisms but may reduce habitat opportunities for other aquatic life such as fish.

In steep headwater streams, management induced reductions in debris loading relative to typical, natural levels may occur in several ways (fig. 4). Cleanup operations themselves may be "over zealous," removing valuable components of habitat for fish and other organisms (Froehlich 1973, Brown 1974, Bustard and Narver 1975). Management activities also result in increased probability of channel flushing by debris torrents by two mechanisms: (1) by increasing the probability of debris avalanches which trigger debris torrents and (2) possibl by altering the size distribution of debris in streams.

Impact of management activities on debris torrent occurrence is reflected in terms of high levels of debris torrent activity (torrents/km^2 per yr) in clearcut and road right-of-way areas relative to forested areas (table 1). The management impact has resulted primarily from increased occurrence of debris avalanches from hillslope areas (table 2) which may lead directly to debris torrents down stream channels. Based on the few relevant studies in the Northwest, cutting alone may increase debris avalanche frequency by several times and roads have an even greater impact (table 2). It should be noted, however, that inventories of both debris torrents and avalanches examined roads constructed mainly before 1970, so more modern roading methods have not been evaluated.

In some areas, particularly in the steep, highly dissected terrain of the Oregon Coast Ranges, changes in the size distribution of debris in headwater channels may also result in increased debris torrent activity. One possible mechanism of triggering torrents would involve the following sequence of events: large stable debris is removed, but smaller material which is floatable during extreme flows is left in the channel; unchecked by massive, stable pieces, the floatabl material is moved downstream in high flow events; after 10 to 20 m of movement, the debris may have sufficient mass and momentum to move very large pieces of debris, thus initiating a debris torrent. Occurrence of torrents may be less likely where the potential buildup of moving fine and intermediate-sized debris is checked by very large logs every 5 to 10 m along a channel. The potential role of fine and intermediate-sized debris in triggering massive torrents may be analogous to use of the small charge in a blasting cap to ignite large explosive charges.

Management activities also reduce stream debris loading by thinning and harvest operations which remove standin

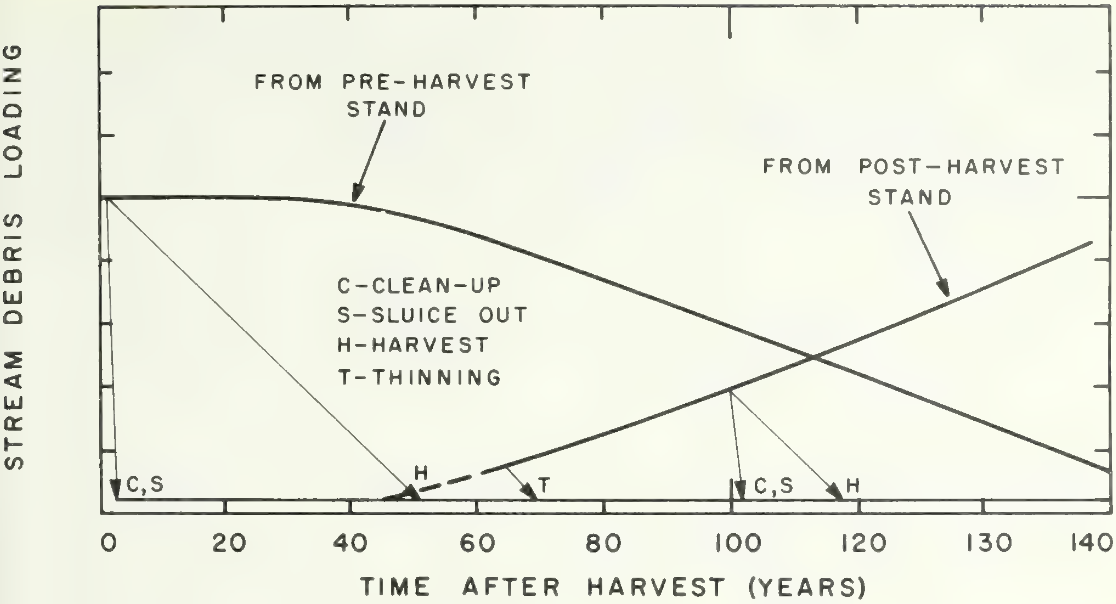

Figure 4.--Hypothetical potential changes in stream debris loading due to management activities in and around steep, headwater streams. Cleanup and sluice out mechanisms involve abrupt removal from the channel. Thinning and harvest remove standing trees that had been the potential source of stream debris.

Table 2--*Debris avalanche activity in forest, clearcut, and road right-of-way areas*

Site	Period of record (year)	Area		Number of avalanches	Avalanches per km^2 per year	Frequency of avalanches relative to forest rate
		Percent	km^2			
Stequaleho Creek, Olympic Peninsula (Fiksdal 1974)						
Forest	84	79	19.3	25	0.02	x 1
Clearcut	6	18	4.4	0	0	0
Road right-of-way	6	3	0.7	83	1/ 20.0	x1000
Alder Creek, western Cascade Range, Oregon (Morrison 1975)						
Forest	25	70.5	12.3	7	.02	x 1
Clearcut	15	26.0	4.5	18	1/ .27	x 14
Road right-of-way	15	3.5	0.6	75	1/ 8.3	x 415
Selected drainages, Coast Range, S.W. British Columbia (O'Loughlin 1972, and pers. comm.)						
Forest	32	88.9	246.1	29	.004	x 1
Clearcut	32	9.5	26.4	18	1/ .02	x 5
Road right-of-way	32	1.5	4.2	11	1/ .08	x 20
H. J. Andrews Experimental Forest, western Cascade Range, Oregon (Swanson and Dyrness 1975)						
Forest	25	77.5	49.8	31	.02	x 1
Clearcut	25	19.3	12.4	30	1/ .10	x 5
Road right-of-way	25	3.2	2.0	69	1/ 1.4	x 70

1/ Event frequency is significantly different (P <0.01) from forest rate.

trees, the future source of large debris for streams. This combination of management impacts directly in a stream and on adjacent forest vegetation is likely to result in marked, long-term reductions in stream debris loading (fig. 4).

Case Study

The characteristics of potential management impacts on the movement of stream debris may be examined in a selected drainage basin. The 700-ha Cedar Creek drainage in the Coast Ranges presents a useful, though perhaps extreme, example. Figure 1 shows the history of timber harvest and the drainage network in terms of U.S. Forest Service stream classification and stream orders in this basin.

Figure 5 shows the history of debris torrents as determined from interviews with knowledgeable people in the area and from field and aerial photograph study. In this 27-year period, there have been 22 inventoried debris torrents: 8 initiated from roads, 8 in clearcuts, 5 in forest, and the point of origin of one was uncertain--either road or forest. Most of the road-and clearcut-related events occurred in the first few years after the management activity. Management impacts appear to be greatest where channels had experienced debris torrents under forest in the previous few decades.

The pattern of debris torrent movement has been from class 3 and 4 or first- and second-order channels to class 1 and 2 or third- and fourth-order channels. From 1950 to 1976, debris torrents in this basin have directly impacted 35 percent of first-order stream length, 61 percent of second order, 40 percent of third order, and 15 percent of fourth order. The small steep streams have been scoured to bedrock (fig. 6), and the transported debris accumulated in the larger, low gradient channels (fig. 7).

The pattern of debris torrent occurrence in the watershed has some

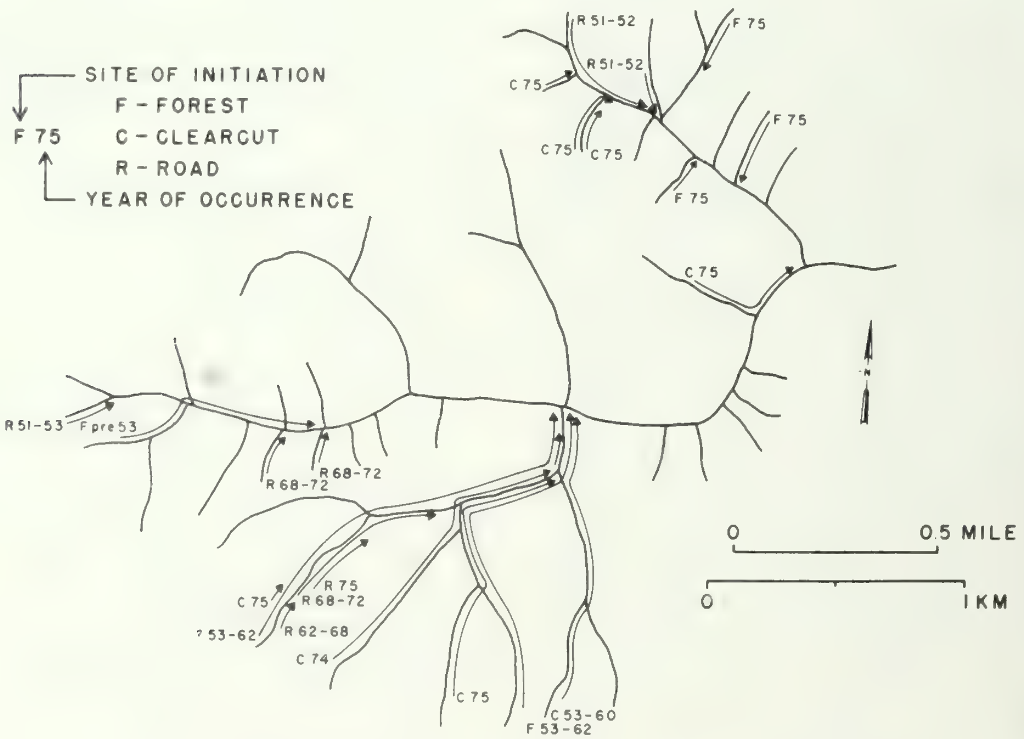

Figure 5.--Debris torrent tracks for 1950-1976 in Cedar Creek.

Figure 6.--Debris torrent scoured channel in South Fork of Cedar Creek.

Figure 7.--Debris jam at end of torrent track in South Fork Cedar Creek. Note figure in upper center of picture.

potentially useful management implications. Figure 8 shows the generalized long profile of the south fork of Cedar Creek and the elevations and channel gradients at the top and bottom of torrent tracks. Events which started above 350-m elevation head in long, straight channels with gradients that may exceed 80 percent. These events ran long distances downstream until setting up at channel gradients of 3 to 11 percent and (or) at abrupt changes in channel direction. The shorter tracks were initiated at lower elevations where debris avalanches entered the channel from short, steep (> 60 percent) tributary draws. These observations suggest that the greatest return on management efforts to minimize stream damage would come from protecting the heads of relatively long, straight, torrent-prone channels.

The general pattern in this watershed has been an increased probability of channel flushing in headwater streams and massive sediment and debris accumulation in intermediate-sized streams. Much of the headwater stream channel length has been cleaned down to bedrock, and timber harvest of surrounding vegetation has removed the source of future large debris for the channel. Repeated timber harvesting will indefinitely prevent the stands from producing large debris for the channel. Therefore, sluiced out or intentionally cleared headwater streams cannot return to levels of debris loading and concentrations of wood and wood-created habitat typical of natural streams.

The massive accumulations of sediment and organic debris at the ends of torrent tracks are probably of greater concern because of their direct impact on fisheries and other resources. Debris jam removal is costly and only minimizes the impact of an event when much of the impact has already occurred. Greater understanding and appreciation of processes of debris jam formation are needed so the occurrence of jams may be minimized

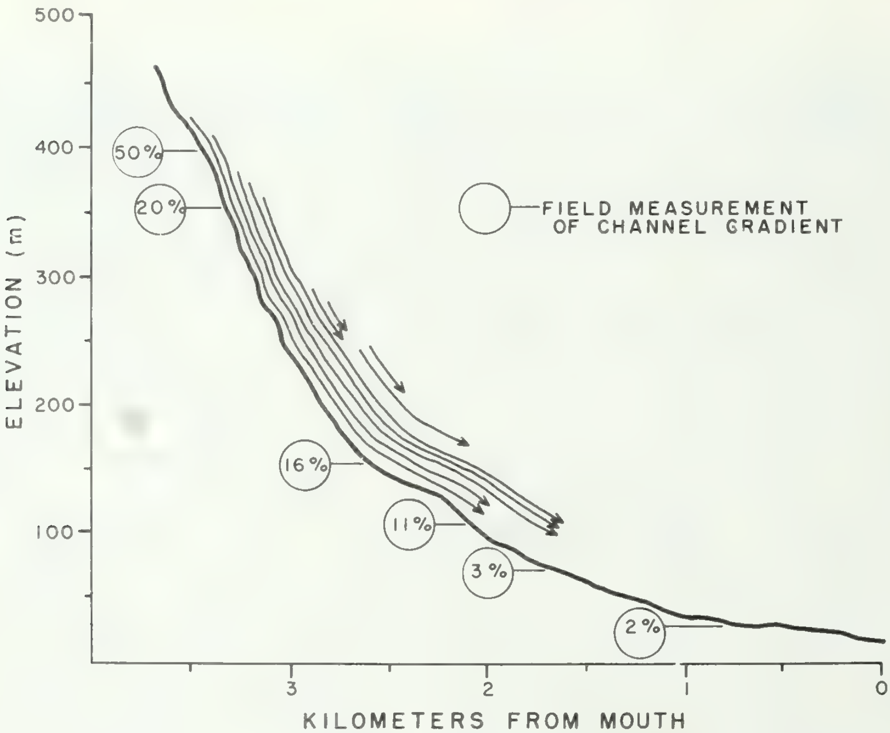

Figure 8.--Generalized long profile of the South Fork and distribution of debris torrent tracks (arrows) with respect to elevation at top and bottom of track.

Summary

Large organic debris is a principal actor determining the biological and ysical character of small and inter-ediate-sized streams in forested ndscapes of the Pacific Northwest. ebris enters streams by blowdown, ndercutting of streambeds, and mass ovement processes on adjacent hillslopes. ebris is moved through channels by otation at high water, in torrents, d as dissolved and fine particulate atter following breakdown by wood ocessing organisms.

Water and sediment routing in annels is controlled by large ebris which may create a stepped ofile. Stream energy is thereby ssipated at the relatively short, eep sections of channel so that much the stream area may have a gradient ss than the overall gradient of the lley bottom.

Debris in streams creates habitat r aquatic organisms both by serving rectly as a substrate and by modi-ing streamflow to form depositional eas. Activity of consumer organisms nds to be concentrated in areas of od and wood-created habitat. In disturbed first-order streams, er 50 percent of total stream area y be comprised of wood and wood-eated habitat; and in third-order reams, it may exceed 25 percent.

Large pieces of debris reside in reams for decades and even longer an a century. This long residence me results in a continuing concen-ation of debris in streams during e 100+ years of stand recovery llowing wildfire, except when debris rrents flush channels.

Management activities directly ter debris loading by addition or moval of material and indirectly by creasing the probability of debris rrents and by removing standing reamside trees. The importance of bris avalanches in triggering debris rrents suggests that torrent prevention i best practiced by minimizing hillslope ilures rather than managing stream bris. Of course, debris torrents ccur in forested areas, and most eep channels have been repeatedly uiced out in the past 10,000 years. Cearcutting and road construction, hwever, may increase the frequency of debris torrents. Inventories of debris torrents in two western Oregon watersheds revealed increases in debris torrent frequency of about 4 and 9 times for clearcuts and 40 and 130 times for road rights-of-way relative to the frequency in forested areas. Most of the roads in these areas were constructed before 1970, so the effects of more modern roading methods has not been evaluated. Repeated logging along headwater streams without buffer strips will prevent small streams from recovering large organic debris loads typical of undisturbed streams.

By this combination of factors, the character of small and intermediate-sized streams over large areas of the Northwest landscape is being substantially altered by forest practices. Neither the extent of these alterations nor the long-term biological consequences are understood. The situation should be examined from a perspective encompassing both general patterns over broad areas as well as the details of site-specific studies.

A program to maximize future options for good stream management would involve: (1) leaving the natural debris in channels and introducing a minimum of additional debris; (2) leaving a buffer strip to help minimize alteration of the stream area and to serve as a source of large debris for the stream in the future; (3) minimizing debris avalanche potential, hence debris torrent potential, by improved unit and road layout, development, and maintenance.

Acknowledgments

We thank J. R. Sedell (Dep. of Fisheries and Wildlife, Oregon State University) and R. L. Beschta (Dep. of Forest Engineering, Oregon State University) for helpful discussions throughout this project. This study was supported by National Science Foundation Grant No. 7602656 to the Coniferous Forest Biome, U.S. Analysis of Ecosystems, International Biological Program. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station Research Work Unit PNW 1653 generously supplied equipment and facilities. Support was also given by the Siuslaw National Forest and Oregon State University. This is contribution number 280 from the Coniferous Forest Biome.

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GPO

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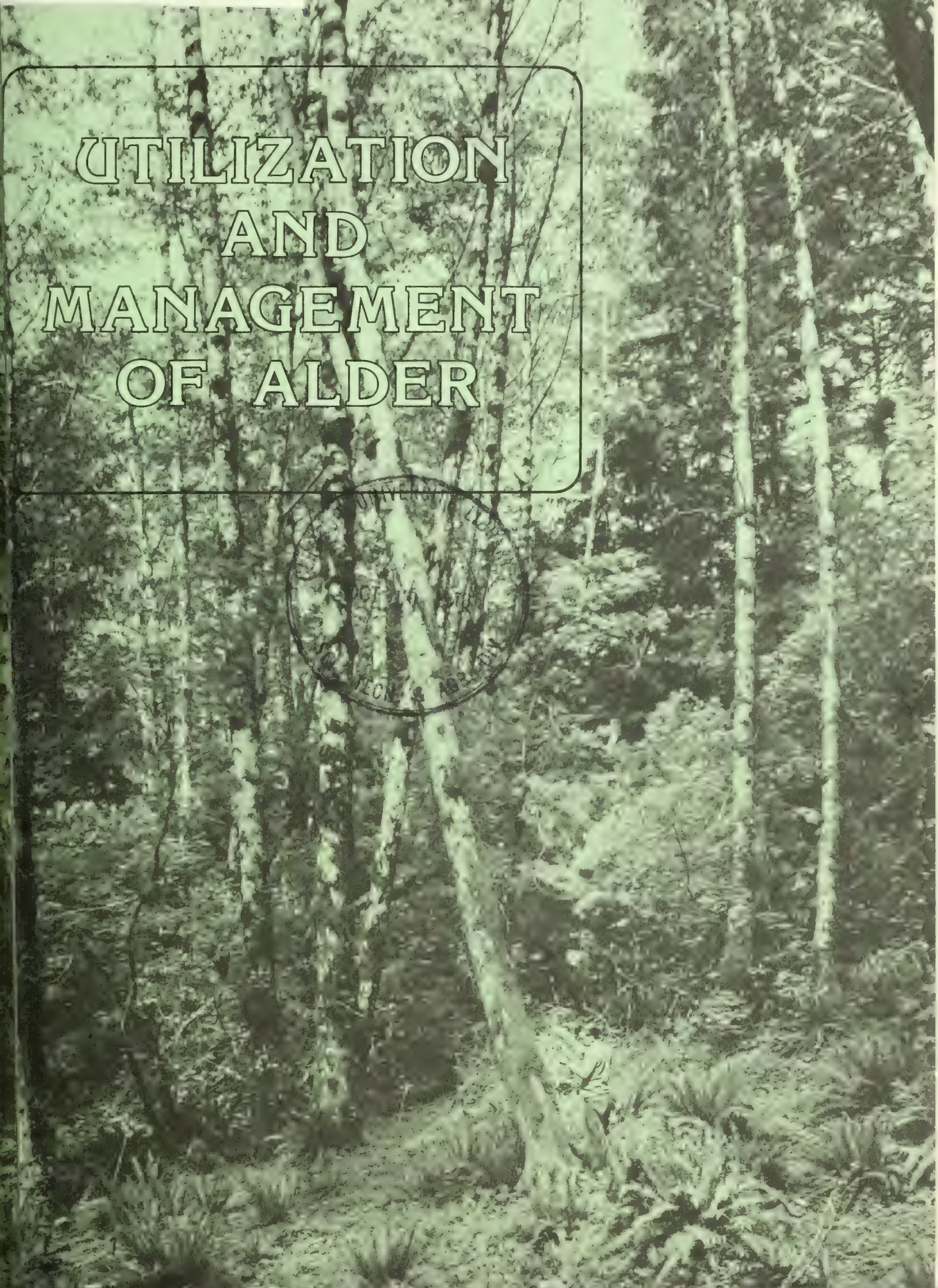
UTILIZATION AND MANAGEMENT OF ALDER



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COVER PHOTO: A stand of red alder at Cascade Head Experimental Forest near Otis, Oregon. The trees are from 14 to 20 inches in diameter. *(U.S. Forest Service photo 325534)*

USDA Forest Service General Technical Report PNW-70

UTILIZATION AND MANAGEMENT OF ALDER

Proceedings of a Symposium
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Compilers

David G. Briggs

Dean S. DeBell

William A. Atkinson

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Portland, Oregon

PREFACE

In the Pacific Northwest and British Columbia, red alder often grows on forest lands following natural or man-caused disturbances. Frequently ignored as a pest or weed, many alder stands have developed to the point where important utilization and management questions are being asked. It is recognized that alder is a fast growing species, and that its rapid early growth may hinder growth of conifers associated with it. It is also recognized that alder has the capability of improving soil fertility, and that it may help reduce root rot problems of conifers. These attributes pose new questions as to whether or not alder should be deliberately managed and, if so, how it should be managed and utilized.

To satisfy this need for information on utilization and management of alder, the University of Washington, College of Forest Resources, the Northwest Hardwood Association, the Pacific Northwest Forest and Range Experiment Station of the U.S. Forest Service, and the State of Washington Department of Natural Resources sponsored a 3-day conference at Ocean Shores, Washington, on April 25, 26, 27, 1977. Speakers from throughout the region covered all aspects of alder utilization and management, while speakers from eastern and southern hardwood areas provided broader perspectives on hardwoods in general. The conference examined questions such as whether alder should be considered a weed problem to be utilized and eliminated in favor of conifers, or whether it should have a long-term role in regional timber supplies.

Papers on all but three of the topics discussed at the Alder Conference are included in these proceedings. Abstracts prepared for the remaining three topics are also included. Thus, this document can serve as a comprehensive, state-of-the-art summary on utilization and management of red alder. It can also be used to assess information needs and determine priorities for future research.

Because hard data on red alder are very limited, the compilers wanted to capture the experience and observations of people working with the species. We also encouraged speculation regarding future supplies, markets, and management. To be consistent with such intent we have exercised very little technical censorship in compiling the proceedings. The authors are responsible for technical content and presentation of their respective papers.

ACKNOWLEDGMENTS

It would be impossible to express our appreciation to all the individuals and organizations that contributed to the success of this conference and the compilation of papers contained in this volume. There are several, however, who deserve special mention.

The initial concept for the conference began as a result of increasing inquiries for information on alder from foresters, researchers, and alder manufacturers. In the fall of 1976, a planning committee was established which refined the general conference concept into a well-defined program and recruited many of the speakers. The planning committee consisted of:

Dr. William Atkinson	College of Forest Resources University of Washington, Seattle
Mr. Sandy Bremner	Export Pacific Inc. Tacoma, WA
Mr. David Briggs	College of Forest Resources University of Washington, Seattle
Dr. Dean DeBell	Pacific Northwest Forest and Range Experiment Station Forestry Sciences Laboratory, Olympia, WA
Mr. Donald Hopkins	Department of Natural Resources State of Washington, Olympia
Prof. Reid Kenady	College of Forest Resources University of Washington, Seattle
Dr. Chadwick Oliver	College of Forest Resources University of Washington, Seattle
Mr. Thomas Prevette	Northwest Hardwoods, Inc. Arlington, WA
Dr. Bruce Rottink	Central Research Division Crown Zellerbach Corp. Camas, WA
Dr. Robert Strand	Central Research Division Crown Zellerbach Corp. Camas, WA
Dr. Jack Winjum	Centralia Forest Research Center Weyerhaeuser Company, WA

The efforts of this committee and the commitments of individual authors in devoting time and effort for this conference resulted in an excellent program. The moderators: Mr. Donald Hopkins, Washington Department of Natural Resources, Mr. Thomas Prevette of Northwest Hardwoods, Inc., and Dr. Robert Romancier of the Pacific Northwest Forest and Range Experiment Station did a most appreciated job of running the program and keeping to the time schedule.

Ms. Pat Davis of the College of Forest Resources was responsible for overall coordination and accommodations.

We wish to acknowledge the contribution of the Editing and Publication Group of the Pacific Northwest Forest and Range Experiment Station.

D. G. Briggs
D. S. DeBell
W. A. Atkinson

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ATTITUDES TOWARD RED ALDER IN THE DOUGLAS-FIR REGION

ROBERT F. TARRANT, Director
Pacific Northwest Forest and Range Experiment Station
USDA Forest Service
Portland, Oregon

ABSTRACT

A positive change in attitudes toward purposeful management of red alder is increasingly evident. Reasons for this change include critical problems of wood fiber supply and increasing costs of fertilizer materials. Several possibilities for exploiting red alder in forest management programs are discussed in light of its rapid early growth rate and ability to improve soil fertility. Additional research must be done, both in the physical and biological sciences if we are to capture the unique attributes of red alder in improved forest management systems. Red alder must be considered a tree of high potential value in a mature forest economy.

For the past 30 years, I have been particularly interested in the neficial aspects of red alder, a fast-growing hardwood that inhabits reambanks and bottom lands in the Douglas-fir region. This species often vades forest sites following fire or old logging roads and other disturbed tes. My enthusiasm about this hardwood is not always shared by practicing resters whose goal is to maximize timber production, and whose concern ten is to keep alder from hindering the growth of Douglas-fir plantations. would like to talk about how these two diverse viewpoints can come gether and how the role of the forester in managing Douglas-fir must be sed on a sound understanding of the ecosystems involved. If I can minisce a bit about the development of my own attitude toward this most teresting hardwood, it may help set the framework for this conference.

My interest began with observations about the growth of alder and fir d the relationships of soils to tree growth. In 1948, I was making a il reconnaissance in the Wind River Experimental Forest in southwest shington, an area in the Yacolt Burn of 1927. It was a hot day and I had ent most of it working upslope and downslope through a nondescript, llow-foliaged Douglas-fir plantation. Near the west boundary of the rest and about 4 miles from the nearest road, I came upon a shady antation of red alder mixed with Douglas-fir in a 5- by 5-foot spacing.

Perhaps because the day was hot and the mixed forest was unusually cool, stayed there longer than I might have otherwise. I spent several hours

wandering through the plantation and observing its unique characteristics. First, it was probably several degrees cooler than the surrounding Douglas-fir plantation. In addition, the foliage of the Douglas-fir in the mixed plantation was exceptionally dark green. The needles were more abundant and larger than those on trees in the Douglas-fir plantation. And the surface of the forest floor was entirely different.

When I returned to the office, I asked the pioneer Douglas-fir silviculturist, Leo Isaac, about the history of this plantation. He told me that after the fire--one of the region's worst--tree planting crews worked in the cold in March 1929 to reestablish the forest. He recalled that, during a lunchbreak around a warming fire, one of the planters said that if there had been a stand of alder on that ridge he'd have bet $5 the fire would have stopped right there. Intrigued by the ensuing argument, Isaac obtained some alder seed and arranged to have it grown in the Wind River Nursery.

By the time the alder seedlings were ready to plant, however, planted Douglas-fir seedlings were already growing at the planting site. As it turned out, the delay in planting the alder was serendipitous. First, planting the alder 4 years after the Douglas-fir enabled the slower growing fir to compete on an equal basis. Second, the alder seed had been collected at sea level, but the resulting seedlings were planted at an elevation of about 2,000 feet. As a result, frost killed the alder back to its root crowns each of the next two winters, again helping the Douglas-fir keep pace with the alder.

When I first saw the plantation in 1948, it was 19 years old in a remote part of the Experimental Forest where not many people had been; and aside from Leo Isaac's reminiscences, there was little record of detailed observation. Obviously, few people knew about the plantation, and fewer yet had any idea of the lessons it held for forest managers.

A preliminary study showed some striking differences between Douglas-fir trees in and outside the mixed plantation. Measurements indicated that the alder and fir trees were the same average diameter in the mixed stand, but that dominant Douglas-fir were larger in the mixed stand than in an adjacent pure fir plantation. In addition, the total volume of wood produced in the mixed plantation was more than twice that of the pure Douglas-fir plantation. Other apparent beneficial effects were also noted in the mixed plantation. For example, the form class was higher for fir grown with alder. Total nitrogen content was greater, both in the soil and in the foliage of Douglas-fir. Significant differences were also found in the number and composition of soil bacteria and fungi.

The initial study led to more detailed observations of the influence of red alder on soil properties. After wildfire, the presence of alder substantially increased organic matter and nitrogen in the upper soil horizons. Other researchers joined in pursuing various facets of the soil-improving characteristics of red alder until today we have amassed a

luable body of information which suggests that this once despised "weed" ee could, in fact, become biologically and economically useful in the uglas-fir region.

Having used the word "weed" in connection with red alder, I will iminate it from further use in this context. A weed is a tree or shrub of w economic value that tends to grow freely and exclude or retard more luable plants. There is no question that red alder grows rapidly, an tribute that leads to its early dominance over other trees. But the fact at alder grows fast and better on some sites than Douglas-fir is not cessarily a disadvantage. In some cases, if the alder is properly managed foresters, it should be a distinct advantage.

I said earlier that foresters have not always had a positive outlook on d alder. That attitude is longstanding. In the West, conifers have always minated the landscape. A hundred years ago, settlers making their way st passed through a thousand miles or more of gigantic conifers, the likes which had not been known in the East. As these pioneers reached the scade Range, it must have been most impressive to travel through the adow of a forest that towered as much as 200 feet above them. Small nder then that the hardwoods -- bigleaf maple, white oak, madrone, and der--made little or no impression.

The pioneers cleared the forest where they made their settlements and t heavily into the stands of huge old-growth Douglas-fir, western hemlock, d Sitka spruce. The hardwoods were always handy to have around--for ooring, spools and spindles, charcoal, and firewood. But these uses were nor compared with the many structural uses of the more valuable conifers. ter, vast acreages of Douglas-fir were logged and left to regrow naturally. though the conifers are prolific seeders and often regenerate naturally, was red alder that came back first on many sites. But it was considered detriment to establishment of Douglas-fir and other conifers. Little ppened for many years to change those attitudes.

The fact that this major conference is being held to summarize what we ow about alder, however, must indicate increasing recognition of both oblems and potential benefits of red alder in intensive forest management. rther, there appears to be concern on the part of the developing hardwood dustries that large-scale conversion programs will destroy future sources raw materials. Both areas of concern appear to me to represent a sitive change in attitude toward purposeful management of red alder.

I think there are several reasons for the changed attitude toward red der. The first has to do with wood fiber supply. It has become creasingly evident that the supply of old-growth softwood timber is indling. Despite the fact that vigorous new young stands are replacing e old growth, evidence at hand indicates there may well be a waiting riod while these new stands replace the old. Foresters are very conscious w of the need not only to better utilize the softwood resource but also to plore other potential sources of wood fiber.

How does the potential of red alder relate to our concern about softwood timber supply? When we attempt to stretch the wood fiber resource as far as possible, the rapid early growth of red alder becomes of major interest. On some sites, this rapidly growing tree can greatly outproduce Douglas-fir at ages up to about 30 years. These growth rates are for unmanaged, genetically unimproved stock. This attribute of red alder might be exploited not only for obvious uses such as pulp and other reconstituted fiber products but also as a means of capturing solar energy in the form of so-called energy plantations.

Another factor that has probably influenced attitudes toward red alder today is the high cost of fertilizers. Maintenance of soil fertility and soil stability is critical to continued, intensive production of wood fiber. A considerable amount of fertilization of forest stands has been carried out with urea, a product derived from natural gas. The short supply of natural gas and the rapid increase in fertilizer cost raise questions about availability of fertilizer in the future. The potential for using red alder or other nitrogen-fixing plants to complement or replace inorganic fertilizers is generally recognized.

In this connection, red alder as a source of nitrogen offers the availability of a natural alternative to a chemical one: in short, the attractive philosophy of organic gardening versus inorganic gardening.

There is an inherent feeling among many people I talk to that we should be able to utilize a commercial tree species that grows as fast as red alder rather than spend valuable forestry dollars to get rid of it. Yet, the fact remains that in our predominantly softwood timber economy, the value of red alder is today little appreciated.

The alder forest type currently occupies about 15 percent of the commercial forest land base in western Washington and western Oregon (3.5 million of 23.5 million acres). Although alder wood has many favorable qualities, current market conditions do not make it attractive to the landowner. Thus, conversion from alder to the original conifer type is proceeding rapidly on State, Federal, and industrial forest land.

The economic incentives for growing alder could be increased if existing markets could be improved or new products and markets developed. Markets for small-size logs are especially needed, because logs under 8-inch upper stem diameter generally represent more than half the stem volume. Such material returns little, if any, stumpage value to the landowner. There appears to be no united effort committed to an aggressive improvement of red alder markets. As a result, there are few incentives to harness the rapid wood-producing capacity of red alder.

No one can predict with any certainty future demands as to form of forest products. The rapidly increasing population and promise of technological advances seem to argue for greatly increased demand for reconstituted wood fiber products at the expense of solid wood timber products as we now know them.

Radical changes in concepts of forest management will be required in ler to take advantage of the more attractive selling points for alder. fessional foresters must take a hard look at preconceived ideas that e developed in a region geared largely to harvesting the bounty of -growth conifers.

Such innovative concepts are being advanced elsewhere. Pulpwood ations of 10, 5, or even 2 years are being considered in the southeastern ted States. There, sycamore planted at 4- by 4-foot spacing can yield e than 10 tons of green wood per acre annually. Harvesting, which may ur at intervals as short as 2 or 3 years, will be done mechanically. An imated 350-400 tons of green wood could be harvested over a 30-year iod (the usual rotation for pine pulpwood) by cutting and replanting amore at 5-year intervals. The growth potential of sycamore is much the e as that of red alder.

Several possibilities for exploiting red alder in an enlightened est management program are immediately evident. The enhancement of the rogen capital of the forest ecosystem is of major consideration under hly intensified forest management. Just as farmers plant legumes to ntain soil nitrogen for agricultural productivity, so might silvicultur-s use red alder in a crop rotation system. Short rotations high in al cubic volume per acre would offer benefits of mechanical harvesting, rt-term investments, reduction of labor costs, and restoring to productive many thousands of acres such as those now lost to powerline rights-of-way.

Another possibility for using red alder to improve the forest ironment is creating mixed plantations of alder and other tree cies. Remember the initial illustration of the increased productivity t can be gained by planting Douglas-fir with alder. The Wind River dy pointed out that total wood production could be doubled, at least at t site.

On moist sites, red alder grows naturally as a fairly permanent and inant component of the vegetation. On such sites, red alder is probably best adapted tree species. Productivity of wood fiber on these and er sites, however, might be increased substantially through admixture another tree species such as black cottonwood. The mixture of *Alnus* and *ulus* is well documented in the literature as compatible and productive.

These are only a few examples of silvicultural systems that might be loyed in a management situation radically different from the one now sting in the Pacific Northwest. We have little experience in red alder agement, a factor that contributes strongly to our present lack of reciation of the potential value of this species for producing wood er, maintaining and enhancing soil fertility, and providing other ironmental benefits.

As a scientist and research administrator, I see a number of research needs that must be met if we are to bring about serious alder management efforts. These needs for new information fall quite logically into two major areas--one of which calls for research in the physical and social sciences and the other which demands silvicultural research.

A. In existing stands--

1. Develop new, economical equipment and methods for harvesting small material.
2. Improve utilization of red alder logs.
3. Develop new markets for red alder products.
4. Develop a better base of economic information to guide management decisions regarding conversion, retention, and interim management of red alder.

B. For future pure stands--

1. Develop effective use of red alder in short crop rotation schemes.
2. Relate patterns of total biomass, wood production, and soil nitrogen enhancement to stand age and density.

C. For future mixed stands--

1. Develop effective use of red alder in mixture with other hardwoods and/or conifers.
2. Determine the density of alder admixture needed to meet nitrogen requirements of mixed stands.
3. Define management regimes that will maximize usable volume and/or wood quality of mixed stands.
4. Determine effect of red alder on site quality aside from the addition of nitrogen (nutrient cycling, organic matter relations, etc.)
5. Determine whether mixed stands including alder are better able to resist disease, insect, and fire losses.

The information gained from this research will certainly have application to the 15 percent of our commercial forests currently classified as pure or mixed alder in western Washington and western Oregon. But it should also have far wider application, perhaps to the more than 60 percent of our commercial forest land that could be improved by the addition of nitrogen. And since alder supplies nitrogen in a number of ways, plantings of alder might be even more beneficial than chemical fertilization with nitrogen.

Those of us in forestry are often conservative in our outlook and are sometimes reluctant to consider new ways of doing things. So were the early-day farmers who fought to control unwanted vegetation such as clover and other aggressive nitrogen-fixing plants that occurred as weeds in their

lds. Scientists had to demonstrate the role of such plants in maintaining l fertility and developed ways they could be managed and harvested for benefit of man.

Now we have an opportunity to do the same thing with red alder. It is ewhat ironic that our efforts to improve Douglas-fir productivity in this ion may be hampered by eliminating from the environment an organism that have helped make these forests productive in the beginning. We already e a considerable amount of information on the beneficial effects of er on the forest environment. The lessons from nature are clear, both m casual observation and from research. Efforts to improve our under-nding of red alder should be increased. But I think we know enough now begin using it in field trials, not only to produce more wood fiber but o to achieve a more productive balance of species and ecological eractions.

It is time to take a new look at red alder. I urge you to treat it as a uable tree species. Let's consider alder, not as an aggressive weed, but a tree with considerable potential in a more mature forest economy.

SUPPLY OF RED ALDER STUMPAGE, ITS QUANTITY AND QUALITY, AND TRENDS IN ALDER STUMPAGE PRICES AND PRODUCT MARKETS FOR THE STATE OF WASHINGTON

GENE R. LITTLE, Supervisor,
Division of Technical Services
Department of Natural Resources
Olympia, Washington

ABSTRACT

There is a sufficient supply of alder for the foreseeable future. Most alder is in private ownership. There will be a tremendous surplus (four times the current harvest) during the 1980's and 1990's. The opportunities for price improvement don't look promising, so we do not see why anyone would intentionally grow alder. To create a favorable climate for the alder industry, attitudes about this species must change.

Introduction

The Washington Department of Natural Resources is involved in three activities related to alder.

1. The Private Forest Land Grading Program:

   All private and intermingled public forest lands in the State of Washington are being classified as to their forest productivity and operability. The program was initiated in 1974 and should be completed by December 1980. The survey correlates forest site to soils.

2. The Productivity Study - Phase II:

   The demonstration study will provide a forest inventory of western Washington from Landsat remotely sensed data. It is to be completed by June 30, 1977. This is an ongoing program. We fully expect it to continue with Phase II, which will continue our economic review, start the Landsat inventory demonstration project in eastern Washington, and test optimum use to which we can put satellite imagery on an operational basis. The program is funded by the Pacific Northwest Regional Commission and provides data on hardwood acreage by 20-year age class, by broad density classes, and for each of five major ownership groups.

3. Small Private Forest Landowner Attitude Survey:

   This survey is designed to give an insight into what small private forest landowners plan to do with their forest land. This infor-

mation will be used to refine the existing Forest Productivity Study for Washington.

A Look at the Resource: Hardwoods in Perspective

Ten percent of the 18 million acres of commercial forest is hardwood (fig. 1). Two and one-half percent of the 1975 total harvest volume of the State of Washington was hardwood. Value of the hardwood inventory is less than one-half percent of the value of the total stumpage inventory, and the figures are going to get smaller. By 2040, we estimate that the acreage base will shrink to about 950,000 acres, or half of what it is now. From these data we conclude that the productivity per unit of conifer acreage is greater than the productivity per unit of alder acreage.

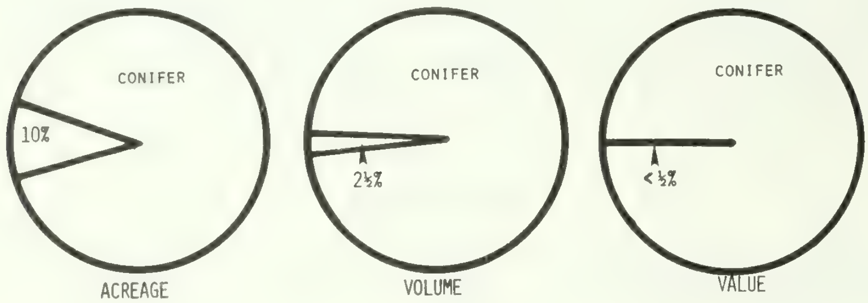


Figure 1.--Hardwoods in perspective.

A Look at the Resource: Where

A schematic of the western part of the State of Washington (fig. 2) shows where those 1.8 MM acres of hardwoods are located. The white area is that part of the State above 1,500-2,000 feet in elevation, where hardwood doesn't grow. The shaded area is the non-urban area (forested) under 2,000 feet in elevation where alder is most apt to grow. Part of this area is lined. The lined area is that part of the hardwood area that has been classified as urban. Much of the current alder base is in the urban area.

About half the inventory comes from the Puget Sound region where most of the urban area exists. The short term supply of alder is coming from the urban area and probably is the result of land conversion to other uses. This finding supports the belief that the alder base will be reduced.

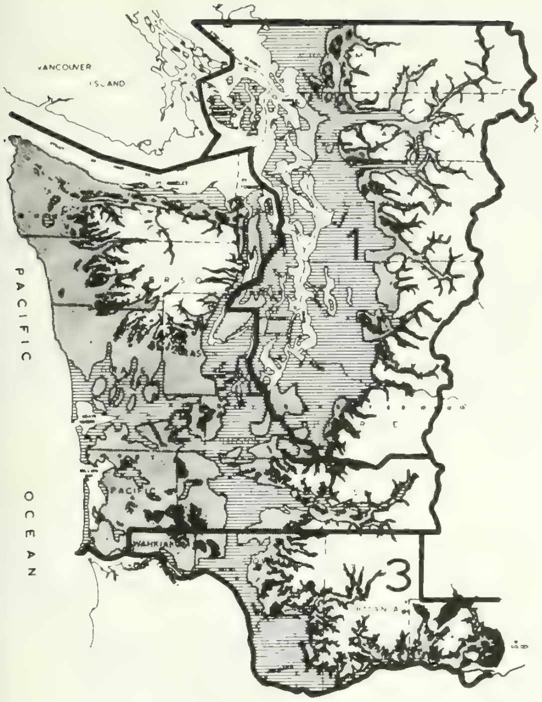
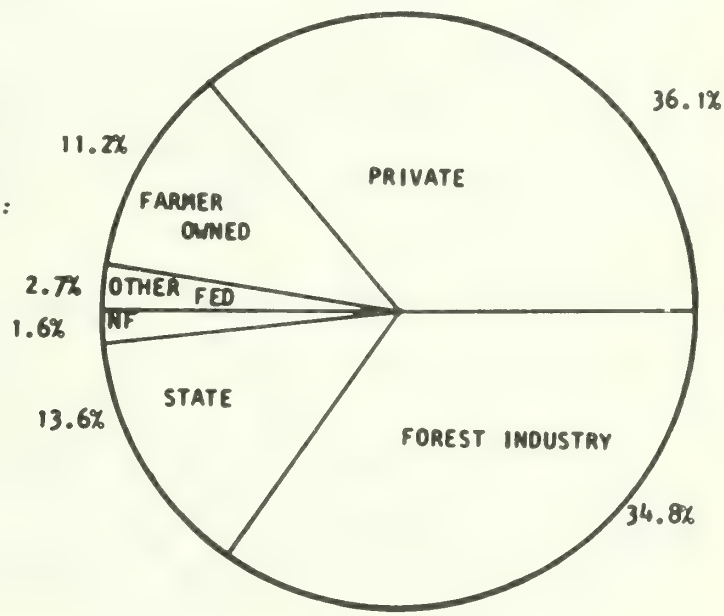


Figure 2.--A look at the resource: Where?

A Look at the Resource: Who

The 1.8 million acres of commercial hardwood is 82-percent private and 18-percent public owned (fig. 3). Consequently, hardwood supply, price, etc. are basically private issues.

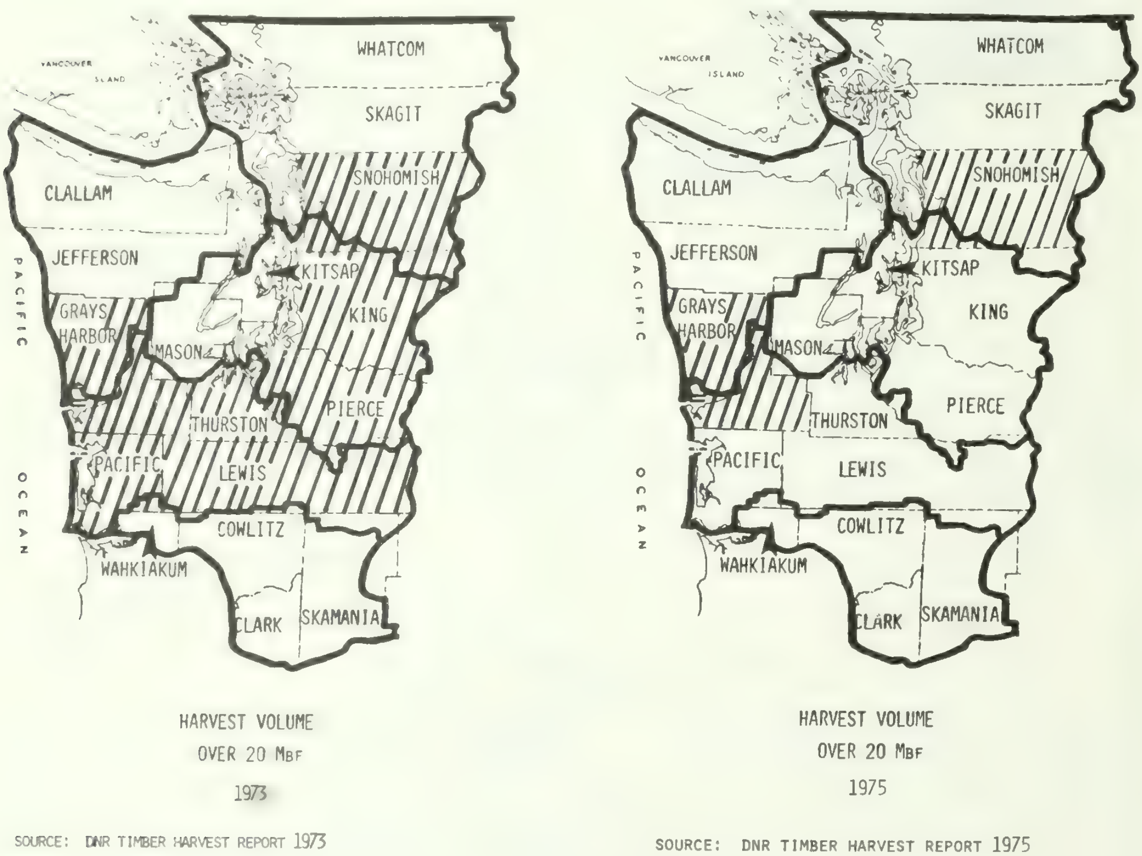
Figure 3.--A look at the resource: Who owns it (acres).



A Look at the Harvest: Where it Comes From

Figures 4 and 5 show those counties with production exceeding 20 MM board feet Scribner per year in 1973 and again in 1975. There was a good market in 1973 but 1975 was a very poor market year.

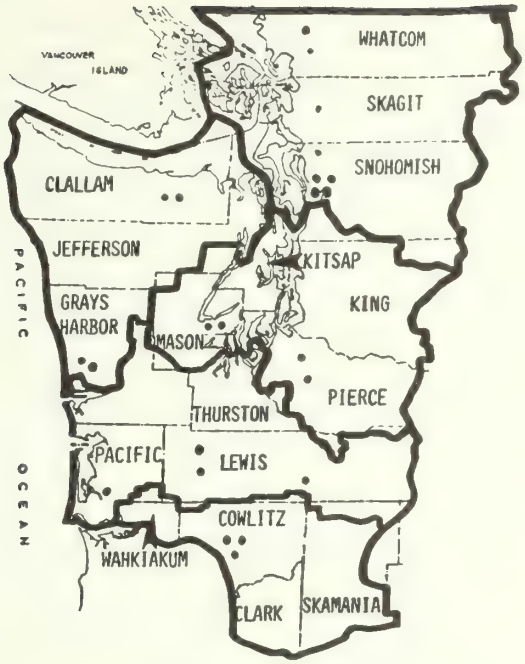
The information in figures 4 and 5 show that Snohomish and Grays Harbor Counties lead in harvest production and produce substantial quantities of alder volume in both good and poor markets. In addition, when we calculate sustainable harvest for each county independently, Snohomish County leads western Washington with Grays Harbor and Lewis Counties following. Snohomish, Lewis, and Grays Harbor Counties consistently rank one, two, and three in harvest and inventory volumes.



Figures 4 and 5.--A look at the harvest: Where it comes from.

A Look at the Harvest: Where it is Processed

Figure 6 shows both the location and size of sawmills. Smaller circles indicate those mills that produce from 0 to 40,000 feet of alder volume per daily shift. The larger circles show those mills producing from 40,000-79,000 board feet of alder per daily shift.



MILL LOCATIONS

SOURCE: DNR MILL SURVEY AND 1976 FOREST PRODUCTS DIRECTORY

Figure 6.--A look at the harvest: Where it is processed.

The consumption of these mills is mostly sawlog grade volume and represents about 30 percent of the harvest potential of the areas that are logged. The remainder of the volume is, for the most part, unused pulp. The industry is composed of small, family operations. Because the mills are small, the industry is more mobile. Mill operation can be sporadic, consumption can change dramatically, and mill location has a greater tendency to change.

A Look at the Harvest: The Record

So little public harvest exists that data in figure 7 represent private harvest only. Industrial and small private ownership groups harvested in proportion to their ownership up until the mid-1960's. From the mid-1960's until present, the industrial forest ownership group harvested proportionately more alder from their acreage base. Apparently, the industrial forest ownership group can respond more effectively to the sporadic alder markets. We feel that the industrial forest ownership group may be converting land occupied by the alder resource to other uses.

Figure 7.--A look at the harvest: The record.

A Closer Look at the Resource

A closer look at the distribution of acres by age class for the alder land base as it will exist in 1980 is necessary if we are to focus on that part of the alder inventory that will be available to us during the 1976 to 1996 period. Since alder stands are generally mature and ready for harvest at about 50 years of age, we should be interested in that part of the inventory that is now 30, 40 and 50 years of age. The inventory of the mid-1960's has been updated to 1980 (fig. 8). Twenty-one percent of the 1980 land base will be cut in the stands that would have reached 60 years of age. We harvest about 30,000 acres of alder per decade. The 60-year age class represents the approximate decadal harvest for 1970 to 1980. We can, therefore, assume that the 60-year age class has already been harvested. That leaves about 70 percent of the total land base in the 30-, 40-, and 50-year age class--a potential that far exceeds our current harvest.

There are very few acres of zero age, very little 10-year age class and very little, but slightly more, acres of the 20-year age class. Why? We might assume that, as alder stands decline in age, our ability to measure or identify them as alder inventory decreases. Or we may assume that the reduction in inventory as age classes become younger might be the result of a steady increase in conifer management here in the Northwest.

Can we assume, then, that, as conifer management increases and as the Forest Practices laws become more constraining, the alder inventory will decline? What will our alder inventory look like in 30 years?

DESCRIPTION

AGE	ACRES
10	?
20	9%
30	10%
40	43%
50	17%
60	21%

Figure 8.--A closer look at the resource.

A Closer Look: How Did Our Current Base Originate?

Let's take a look at where the inventory that we will be harvesting in the next 20 years came from. The history of our conifer harvest here in the State of Washington (fig. 9) indicates that, in 1929 and 1930, we harvested more acreage of conifer volume in this State than ever before in recorded history. The harvest from that point on went down rather gradually to the volume that we have today.

Heavy harvest volumes, no Forest Practices laws, and less intensive fire control with resulting large wildfires may have produced our current alder base. We have changed our pattern of harvest and land management. The reduction in our alder inventory land base seems to support the theory that improved management produces less alder base.

gure 9.--A closer look: How did our current hardwood base originate?

A Closer Look: Volume

The assumption as to the source of the hardwood inventory is also supported by the three estimates of the inventory of hardwoods (fig. 10). This figure shows that in the 1920's, there was only one-third of a billion board feet of alder. By 1955, the estimate had increased to about 8½ billion board feet of alder; and by the mid-60's, the estimate had increased to about 12 billion feet--an enormous increase.

Let's take a closer look at the inventory for the 1960's. The upper part of the graph (between 7.1 billion and 12 billion board feet) consists of hardwood inventory mixed with conifers. If one were to consider only the stands that were classified as hardwood stands, we would have 7.1 billion board feet of hardwood, averaging 3,900 board feet per acre. If one were to look at only those acres of better stocked hardwoods containing 5,000 board feet per acre and greater, one would have an inventory of 3.6 billion feet on some 380,000 acres, with an average volume of 9,500 board feet per acre. Regardless of the inventory unit selected, one must recognize that there has been a 10- to 30-fold increase in volume in the last 40 to 45 years, depending on what one includes in the inventory.

The two arrows in the lower right-hand corner represent the following: If we were able to successfully manage all the existing alder intensively, this would require a reasonably stable inventory of 6 billion board feet. If, however, that same area were continued at its present level of management we would need a reasonably stable inventory of about 4¼ billion board feet.

These data support our theories on how the alder inventory originated. We have ample inventory to continue at the current level of management, or even more intensively if we desire.

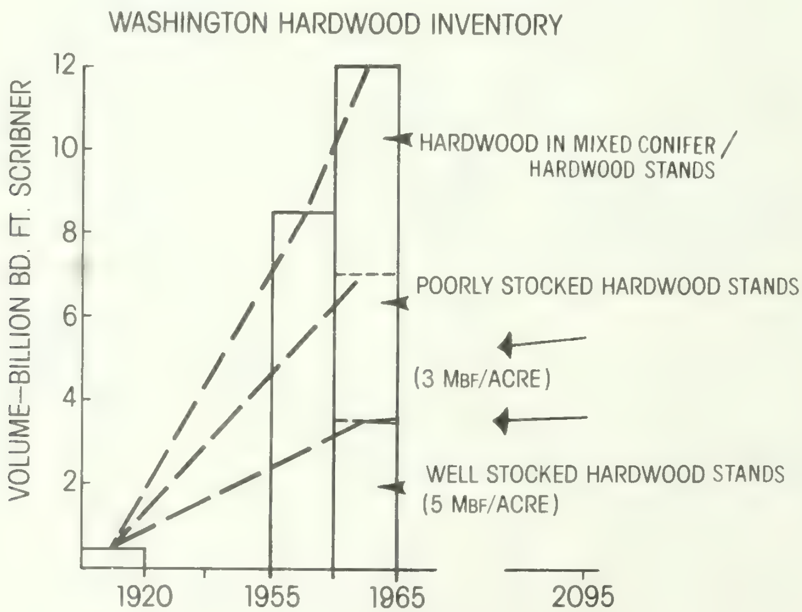


Figure 10.--A closer look: Volume.

A Closer Look: The Average Stand

Figure 11 gives us a closer look at what we consider to be the typical current hardwood stand. It is 40 years of age, exists on alder site index 90, and has an average d.b.h. of 10 inches. The cubic volumes in cubic feet (*CV*), Scribner volumes in board feet (*S*), and number of logs (*#L*) noted in the figure come from DNR Report 31[1] where we find that a high percentage of the stands that make up the inventory are pulp quality.

AN ACRE OF TYPICAL STAND

(80% NBA)

		PERCENT OF STAND ABOVE TOP DIB		
AGE	UNIT	8"+	10"+	TOTAL
	CV	43	3	2,100
30	S	67	6	5,800
	#L	31	4	340
	CV	54	23	3,100
40	S	74	34	9,900
	#L	38	13	450
	CV	67	31	4,000
50	S	84	44	14,300
	#L	47	17	570

Figure 11.--A closer look: The average stand.

The Harvest: An Overview

Big things are expected from Washington hardwood harvests. Since the mid-1950's, the annual harvest had been erratic, but on an upward trend (fig. 12). In 1975, something happened to that trend. To maintain the upward trend that developed from the fifties through the seventies, a most dramatic increase must occur from the 1975 level in the next few years. Our analyses project the potential harvest at somewhere between 700 and 800 million f.b.m. in the late 1980's. The harvest will then slowly taper off through 2045 to somewhere between 130 and 270 million f.b.m. per year and remain at that level for as long as we can calculate. This harvest potential was projected at two levels of management intensity: "Current," which assumes a pattern and level of management which is consistent with today's practices, and "Intensive '75," which assumes a very intensive level of management--the most intensive level of management practiced in 1975.

[1]Chambers, Charles J. 1974. Empirical yield tables for predominantly alder stands in western Washington. State of Washington, Dep. of Natural Resour. Rep. No. 31, Olympia.

We feel that it is going to take an enormous change in our current pattern of logging to use the potential that is available in the near future. If this potential is not used, we will not have much time to store it on the stump for future use as alder stands break up at older ages. Thus, there is some urgency to create consumption for the fiber that will be removed from alder sites converted to conifer production or to other competing land uses.

Is there anything that we see taking place now or in the near future that would cause us to believe that the excess in terms of two to four times our current annual harvest could be used economically and profitably?

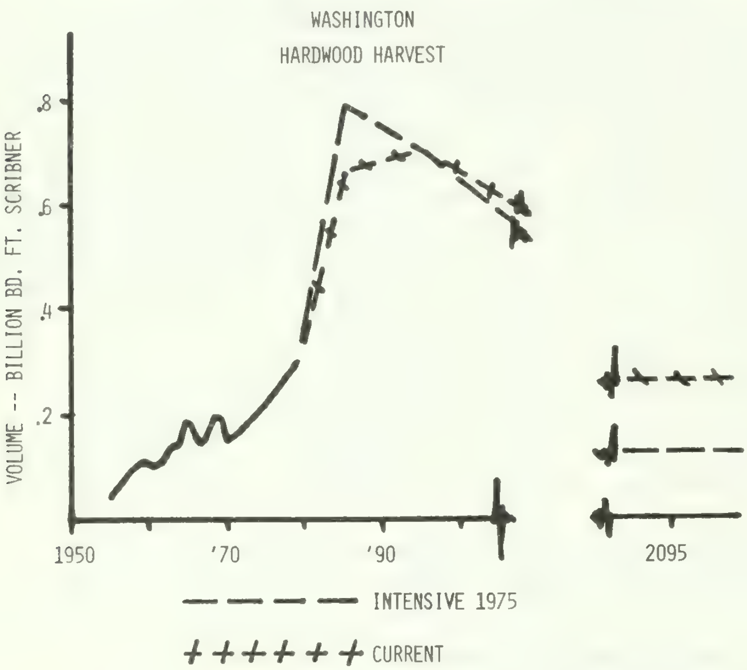


Figure 12.--The harvest: An overview.

The Hardwood Inventory and Its Potential—A Summary

The major portion of the alder inventory here in western Washington is privately owned. That ownership comprises a very small percentage of the total commercial forest land base in western Washington. Most of the inventory and the harvest comes from Snohomish, Lewis, and Grays Harbor Counties. The mill capacity is evenly distributed and consists mostly of small mills. There will be a huge increase in available inventory in the next 20 years, most of which will be lost if not logged during these two decades. Most of the existing inventory apparently was created in the thirties; and as Forest Practices laws and intensive management programs have increased, the acreage of hardwood base has decreased proportionately. The inventory of the sixties will shrink to about half its current size by the year 2000 and beyond, but this inventory will sustain considerably more annual harvest than we are now experiencing. The inventory consists of stands which contain small percentages (30 percent or less) of sawlogs and huge volumes of pulp material which is currently unused and left on the ground. It is going to take a huge change in our hardwood industry to use the volume available in the foreseeable future.

Markets and Price Trends

SAWLOG PRICES:[2] [3]

Price has increased (fig. 13) at the same rate as increased costs of labor and equipment used in logging. As the figure indicates, the trend line is up, but only keeps up with increased costs. Price, however, does not change with quality.

Figure 13.--Alder sawlog prices (#3 sawlogs, FOB MILL).

STUMPAGE PRICES:

If the data in figure 14 were plotted without inflation, the line would show a down trend: Price increase is not even keeping up with inflation. The cost of production, however, is rising faster than the price of logs at the mill. Thus, real stumpage prices are probably decreasing. In addition, these stumpage prices may be on the high side because of conversion benefits being built into stumpage and because enough conifer is included with each sale to offset the low alder stumpage.

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[2] Prices include inflation.

[3] As reported to DNR by local mills.

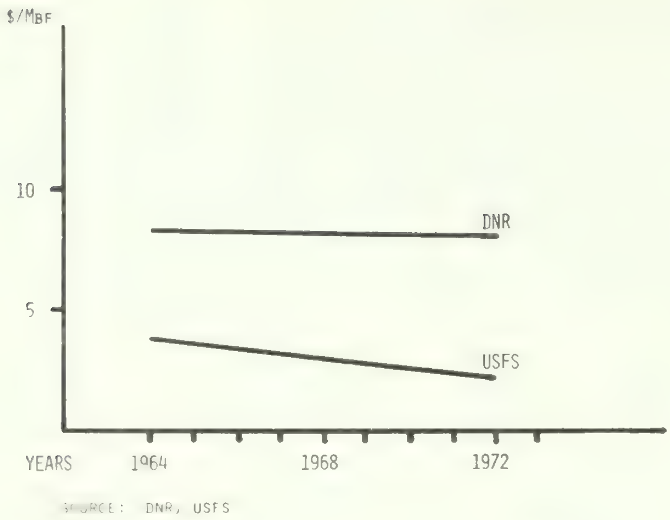
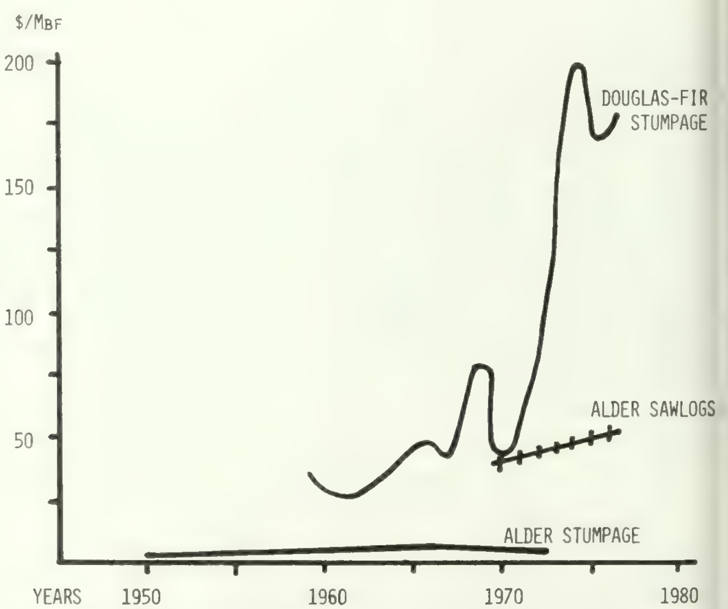


Figure 14.--Stumpage prices: Alder.

PRICES IN PERSPECTIVE

Figure 15 compares the hardwood stumpage prices with Douglas-fir stumpage prices over the same period of time. We'll illustrate the relative investment opportunities of alder stumpage as opposed to Douglas-fir stumpage. These figures for Douglas-fir come from Region 6 stumpage data. Department of Natural Resources stumpage for Douglas-fir is consistently higher. Incidentally, the difference between the price of sawlogs as plotted above and the price of hardwood stumpage probably represents the cost of productio

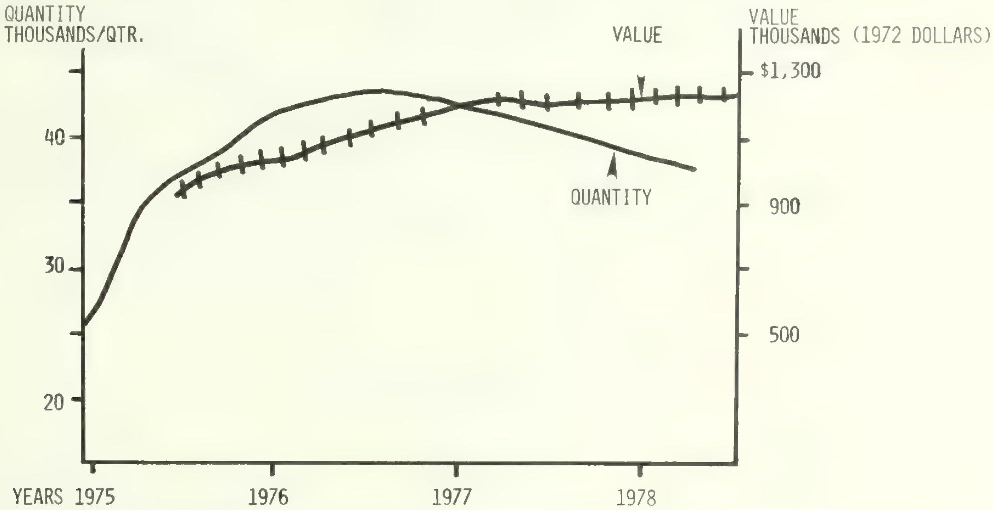
Figure 15.--Price trends.



SOURCE: DNR INTERNAL DOCUMENTS; ED HOLT, "PRODUCTION PRICES, EMPLOYMENT AND TRADE" USDA.

HOUSING MARKETS:

As population increases housing permits may increase as shown in figure 16 thru mid-1976. In the near future we expect a decline in permits, and leveling off in value.

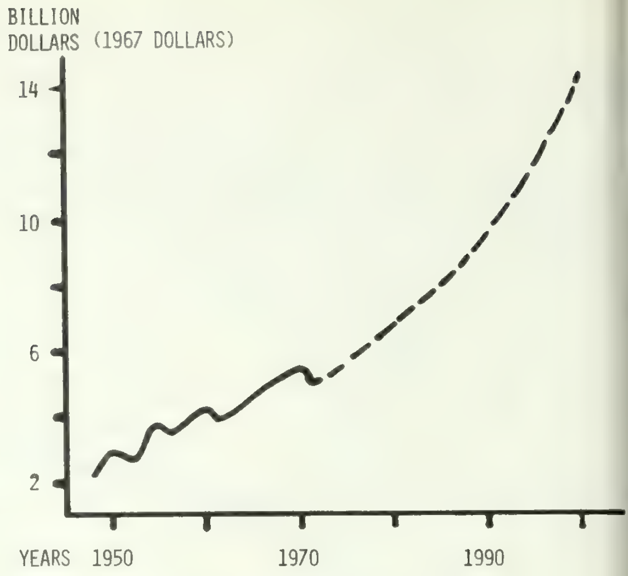


SOURCE: WHARTON EFA, BOEING COMPUTER SERVICES, INC., FOURTH QUARTER, 1976

Figure 16.--Housing permits.

FURNITURE MARKETS:

Peak demand for furniture and cabinets (prime uses of alder) should follow housing starts simultaneously. Although an increasing trend has been projected for household furniture in figure 17, declining numbers in new household formations and housing starts would produce corresponding declines in furniture demand unless tastes and preferences turn to some new fad. Competition from producers of particle board, plastic, fiberglass and metal furniture will have an effect on projections.



SOURCE: USDA, FOREST SERVICE, THE OUTLOOK FOR TIMBER I
THE UNITED STATES

Figure 17.--Household furniture.

Some Questions

IS THERE A SHORTAGE?

Some observers feel that there will be a shortage of sawlogs in the near future. This is not supported by biological information but may be based on some economic fact. No shortage exists, however, when the price for the product satisfies both the buyer and seller. As costs of production rise, cost of product must rise. Thus, shortages that arise will be economic rather than biological.

Alder will be a drag on the market. Forest managers and others may be figuring out how to get rid of it in the most cost-effective manner to make way for other land uses. This may distort the market and price.

THE FIREPLACE DILEMMA

This issue reared its ugly head in the marketplace and complicated the supply issue. In the larger cities, fireplace wood is currently selling for $35-$55 per cord delivered at the yard of the purchaser. This amounts to fr $70-$110 per thousand for wood in fireplace lengths dumped at the homeowner' site. This could be heavy competition to mill owners in these areas who offer from $50-$75 per thousand for sawlogs or, at most, prices that correspond to fireplace wood. No telling what the energy shortage will do to this part of the marketplace.

ACT OF CONVERTING HARDWOOD SITE TO CONIFERS

Hardwood interests really don't have to worry about alder plies in the near future. As you recall, the worst management ion presented provides assured potential of 1972 harvest levels ak year) throughout the next 70 years. In addition, the latest attitude survey of non-industrial private forest landowners eals that only about 25 percent plan to eradicate hardwoods, only when convenient.

L A CHANGE IN QUALITY OR QUANTITY CHANGE THE PRICE?

Price of stumpage is not keeping up with inflation. The huge umes available will tend to depress prices even more and I pect that there is little hope of changing the price structure pay for quality differences in the near future.

PROPERTIES OF RED ALDER *(ALNUS RUBRA* BONG.*)* AND ITS COMPARISON TO OTHER HARDWOODS

L. LENEY
College of Forest Resources
University of Washington
Seattle, Washington

A. JACKSON
Greenacres Consulting Corporation
P.O. Box 386
Kenmore, Washington

H. D. ERICKSON
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

Red alder is compared with several common commercial hardwoods of the United States. The objective is to show that alder is suitable for many products for which other hardwoods of similar structure and specific gravity are used. One advantage of alder is its uniform color of both heartwood and sapwood. A limited test of alder specific gravity showed a range of 0.33 to 0.48 and no correlation with growth rate. Tension wood is shown not to be a problem in alder and not easy to detect. Growth stresses are believed to be more of a problem, causing the splitting of logs and warpage of lumber.

Introduction

Recent literature includes very limited information about research con-
erning the wood science and technology of red alder. Three general reports
n alder include a brief summary of its wood properties (*9*, *10*, *13*).

Heartwood-Sapwood

There is no apparent heartwood in red alder. The center of the log
ross section is no different in color from the wood on the outer part of
he stem. Though there may be what is called physiological heartwood formed
n the center of the larger stems, it cannot be distinguished by color dif-

ference. This lack of heartwood-sapwood difference simplifies lumber grad ing and sorting by eliminating the need for separation of sapwood from hea wood as is necessary for wood such as walnut or sweetgum.

The center of the log may show discoloration due to incipient decay. Irregular discoloration due to stain fungi may also occur, especially in the outer zone. Alder is not decay resistant, and blue stains easily. Pr ventative measures need to be taken from the time the log is cut until the lumber has been dried.

Color

The color of alder changes between the time it is first cut and its final use, depending upon the conditions it is subjected to. When first sawed, the wood of alder is nearly white. It may turn pinkish white after some exposure to air and light. As the wood dries, the color either becom an off-white to ivory or darkens to a reddish or yellow brown. The color and its darkness depends upon temperature and moisture conditions during drying (*1*, *5*). The control of this color change is important because it affects the marketing of alder. Many buyers want only a uniform honey bro Kozlik (*6*) found that presteaming the lumber before drying had a distinct effect on the final color. The color is believed to be the result of chan in the polyphenolic extractives in the wood (*4*, *7*).

Wood Anatomy

Alder is classified, with respect to its wood anatomy, as a diffuse porous wood. As seen in figure 1, there is very little change in the wood structure from earlywood formed at the first of the growing season to the latewood formed at the last of the growth year where there is a slight, ve narrow band of denser wood with few vessels and denser fibers. It is this narrow denser band that makes the growth ring distinguishable and shows as a subdued grain figure on the surface of a planed board.

The pores or vessels of alder are small and quite evenly distributed among the fibers. This gives the wood a uniform grain with a fine smooth texture. Because most of the rays of alder are narrow, they cannot be see without magnification and so do not contribute to the figure as do oak or hard maple. Aggregate rays may occur. These wide composite ray structure can look somewhat like the large rays in oak (fig. 2). Aggregate rays, however, are sporadic in occurrence. They may be abundant in one piece of wood, sparse or entirely absent in others. The figure they cause is not consistent.

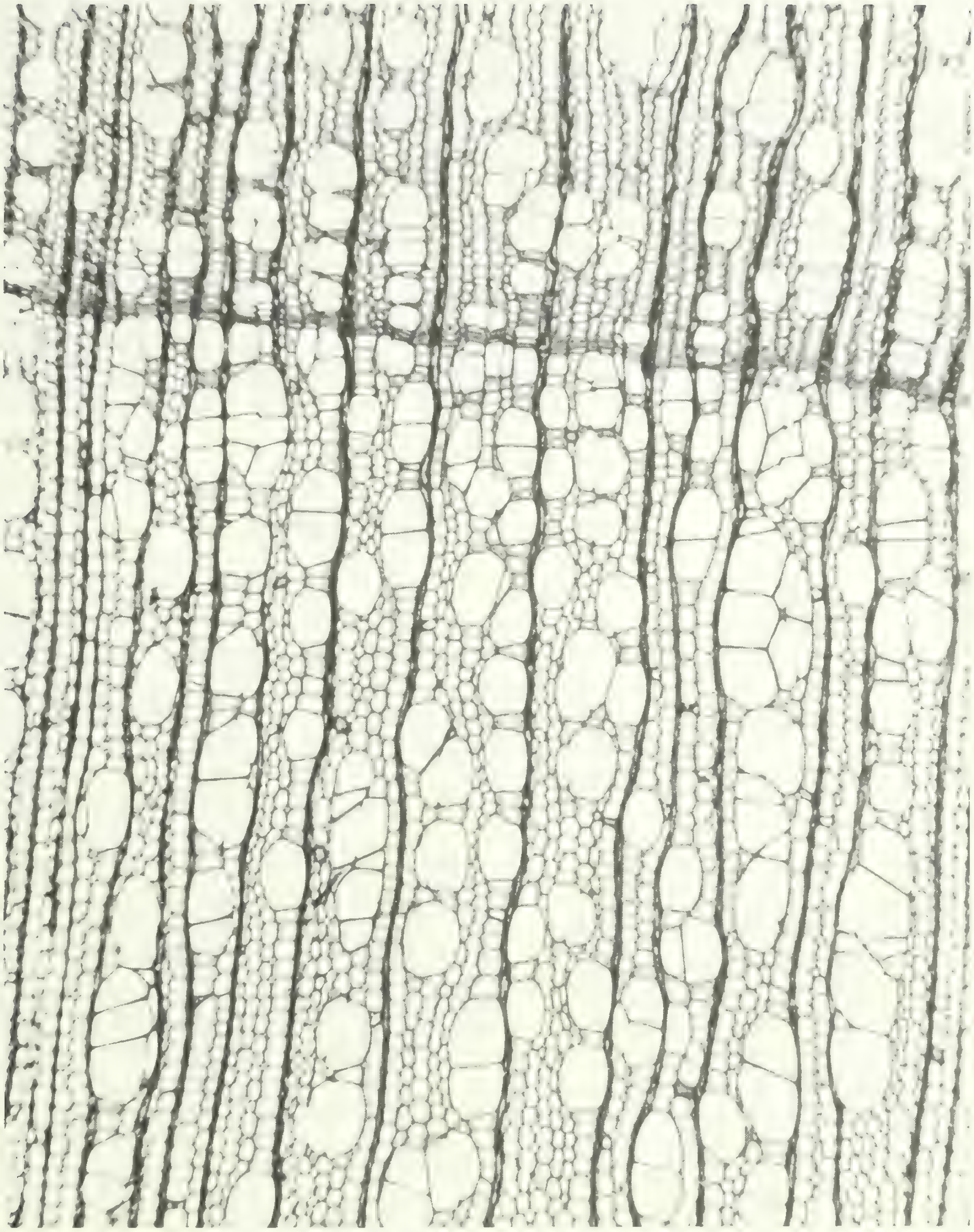


Figure 1.--Cross section of alder showing the change of structure at the ring boundary.

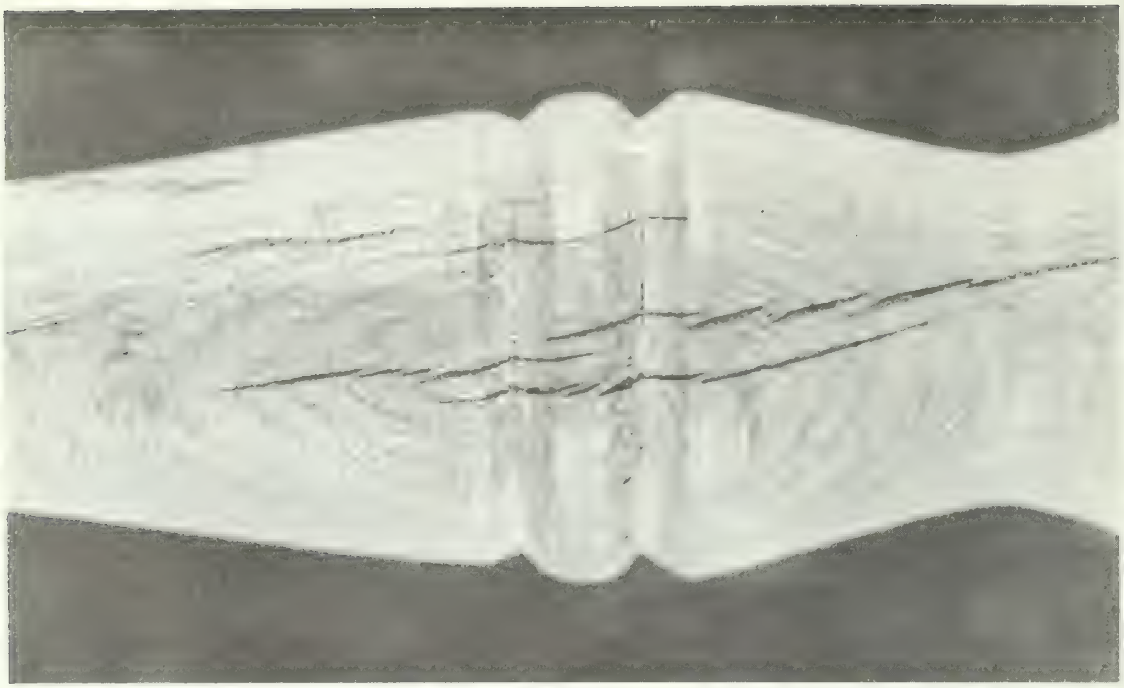


Figure 2.--Aggregate rays show on a turning of alder.

Ease of Working and Finishing

The fine, even texture and moderate density make alder easy to work with tools. It sands and polishes well to a very smooth surface. Since the vessels are small in diameter, there is not the show of vessel lines in coarser textured woods such as walnut. The grain of alder does not sh through a painted surface. It holds paints and coatings very well and ta stain readily (*3*). The subdued grain allows it to be finished in a varie of ways to suit designer taste.

Fiber Use

The fibers of alder average about 1.2 mm long (*2*, *8*). The average lengths for the hardwood species range from 0.6 to 2.3 mm and for softwoo 1 to 7 mm. Alder pulps well and is widely accepted both on the West Coas and in Japan. The chips, however, cannot be stored in piles for 6 months more as there is considerable loss due to deterioration by micro-organism There is a loss of wood substance, and the burst and tear of the pulp is significantly reduced. Methods of treating the chips to retard deteriora in the chip pile have been tried with some success (*11*).

Physical Properties

Physical properties of alder can be shown best by comparing them to several commonly used hardwood species (table 1). For ease of comparison the woods have been assigned an index class for each property to compare each to the other commercial woods of the United States as well as the wo in the table.

Table 1--*Comparison of selected physical properties of red alder and nine other commonly used woods*[1/]

Species	Specific gravity[2/]	Weight at 8% M.C. lb/ft[3/]	Modulus of rupture[3/]	Impact bending	Tension perpendicular to grain	Compression perpendicular to grain	Hardness	Volumetric shrinkage[4/]
Cottonwood	31	20.9	2	2	2	1	1	3
Basswood	32	21.6	2	1	2	1	1	7
Alder	37	24.9	3	2	3	2	3	3
Yellow poplar	40	27.0	3	2	4	2	2	4
Maple, silver	44	29.7	2	2	4	3	3	3
Maple, bigleaf	44	29.7	4	3	4	3	4	2
Sweetgum[5/]	46	31.0	5	3	7	2	4	7
Walnut, black	51	34.4	6	3	6	4	5	4
Birch, yellow	55	37.1	7	6	9	3	7	8
Oak, red	56	37.7	6	4	7	4	7	5

1/ Derived from data in the Wood Handbook (*12*).

2/ Based on green volume.

3/ The range of values for all the commercial woods of the United States is divided intc 10 even index classes with 10 being the highest value.

4/ The lowest figure is best with least shrinkage.

5/ Marketed as redgum and sap-gum.

It is evident that alder is very close to yellow-poplar and silver maple in its physical properties. It is slightly superior to cottonwood and basswood, which are of lower specific gravity, and generally of lesser strength than those woods with higher specific gravity. Alder is better than most with respect to shrinkage. It has the important characteristic of "staying-in-place" by little shrinking and swelling with moisture changes.

Specific Gravity

As can be seen in table 1, specific gravity is a general indicator of certain properties. The first author recently made a limited test of specific gravity as related to growth rate. The end 6 inches were trimmed off boards in a load of lumber being prepared for drying in an experimental dry kiln. From these pieces, 55 specific gravity sample blocks were cut. The blocks were cut so they contained a fairly uniform width of growth rings. The average ring widths of the blocks ranged from 1 to 10 mm. Specific gravities of the blocks ranged from 0.33 to 0.48 with an average of 0.39. There was essentially no correlation between ring width and specific gravity. The linear correlation coefficient was -0.010. If further investigation substantiates this same lack of correlation between growth rate and specific gravity, the objective of maximizing growth rate can be followed without fear of reducing the specific gravity. Whether other properties are affected by variation of ring width will have to be tested. There appears to be a lack of such information in the literature.

Machining and Gluing

Table 2 shows how the machining properties of the woods compare. Alder has a comparatively good rating and should be able to be used interchangeably with most species now used to manufacture furniture or cabinets.

Table 2--*Comparison of machining properties*[1/]

Species	Planing	Shaping	Turning
Cottonwood	1	1	5
Basswood	7	2	4
Alder	6	3	10
Yellow-poplar	8	2	9
Maple, soft	3	4	7
Sweetgum	5	4	10
Walnut	6	5	10
Birch	7	8	8
Oak, red	10	4	10

[1/] Based upon data in the Wood Handbook (*12*). The range of all wood tested is divided in 10 index classes with 10 being the best.

Table 3 shows that alder glues well under a fairly wide range of gluing conditions with glues of a moderately wide range of properties.

Table 3--*Gluing properties*

Class I	Class II	Class III	Class IV
Glue easily for wide range of glue properties and gluing conditions	Glues well with less range of glue properties and gluing conditions	Glue satisfactory with best quality glues and well controlled gluing conditions	Require very close control of glues and gluing conditions
Cottonwood and yellow poplar	Alder, basswood, and sweetgum	Maple (soft), oak, and walnut	Birch and maple (hard)

To summarize these properties, the relatively low density and strength of alder should be taken into consideration in design. Dimensions may need to be increased to compensate when directly replacing a denser, stronger wood. The good machining quality, reaction to glue and finishing characteristics along with minimum shrinkage and swelling makes alder very suitable for use in furniture and cabinet work. In fact, it already has wide use in the furniture industry.

Tension Wood and Growth Stresses

Like a number of hardwoods, alder sometimes has reaction wood of the type referred to as tension wood. Extensive study of this type of wood was started at this College in 1957 by the last two authors of this paper. The usual tension wood characteristics could not be correlated with the uphill or downhill sides of the trees. Microscopic studies failed to demonstrate the general presence of tension wood. In fact, well-developed tension wood is rare in red alder, and the problems usually associated with the conversion of tension wood seldom are cause for concern in the alder industry.

These points are significant because the properties of tension wood are substantially different from normal wood. Tension wood is often difficult to detect. Sometimes it has a silky or dull lustrous appearance. Other times these features are not obvious. Staining techniques and microscopic examination are used to identify gelatinous fibers which are considered to be characteristic of tension wood. The gelatinous layer(s) of the secondary wall have highly organized cellulose molecules of higher than average molecular weight and are often less lignified than normal walls. All stages of development of gelatinous fibers are found in red alder, if it has tension wood.

The vessels are smaller and less frequent in tension wood. Tension wood of red alder has a higher density than normal wood (0.396 vs. 0.360), and the wood formed immediately before and after the tension wood is also more

dense (0.385). Tension wood shows greater longitudinal shrinkage (0.348 percent vs. 0.150 percent). This property is probably the most undesirable for tension wood in product use.

In hardwoods, tension wood often causes problems during manufacture of forest products by producing woolly surfaces when it is sawn, machined, or converted into veneer by peeling. This is especially common with cottonwood. Such surfaces sometimes produce poor glue bonds. Tension wood is more difficult to dry without degrade, and collapse is fairly common. Tension wood makes inferior pulp by the usual alkaline and acid sulfite methods but produces superior pulp by neutral sulfite and mechanical processes. The pulp yields are greater than for normal wood for the alkaline and neutral sulfite processes.

If tension wood is found in red alder, gelatinous fibers are found on all radii of the trees but are most likely found in the uphill radius of leaning trees or associated with areas of previous damage. Heavy concentrations of highly developed gelatinous fibers are rare.

Leaning red alder trees do develop eccentric growth. In our work on 40 leaning trees from eight locations, sampled at four heights (0, 8, 16, and 24 ft above ground), the greatest radius was usually on the downhill side, not the uphill side as normally expected. The uphill radius, however, was greater than the side radius. The degree of eccentricity could not be related to the degree of lean.

The manufacturing problems associated with harvesting and conversion of red alder are not generally due to tension wood, as it is of infrequent occurrence. Rather, the problems are more likely due to growth stresses. Although growth stresses are common in red alder, they have not been adequately studied. When the tree is felled, it will often "barber chair," a problem associated with growth stresses. During sawing, the logs will shift and may even jump out of the carriage dogs, or the logs and lumber will split open at the ends. This is typically caused by growth stresses. Microscopic compression wrinkles are found in the cell walls of such red alder and they strongly indicate growth stresses in the tree.

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AN APPROACH FOR COMPARING THE RELATIVE VALUE OF ALDER WITH OTHER SPECIES FROM FOREST TO END PRODUCT

DAVID G. BRIGGS, Assistant to the Dean
College of Forest Resources
University of Washington
Seattle, Washington

JAMES S. BETHEL, Dean
College of Forest Resources
University of Washington
Seattle, Washington

GERARD F. SCHREUDER, Professor
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

Comparing alder as a renewable species with other species depends on a thorough analysis of a variety of technical and economic data from the system for growing trees through their end use. All too frequently, detail and components of the system are overlooked in policy analysis because a consistent and comprehensive format of appropriate data is not available.

What is needed is a framework that incorporates diverse information on the technical, economic, labor, energy, and environmental aspects of production systems, captures those characteristics important to policy decisions, and thus facilitates the study of the role of alder as a source of materials in comparison to competing alternatives.

This paper explains the Reference Materials System (RMS) adapted by the National Academy of Sciences' Committee on Renewable Resources for Industrial Materials. RMS is suggested for use in examining the complex issues concerning alder management and utilization.

Introduction

During this conference, many aspects of alder utilization and forest anagement will be discussed; and comparisons with alternative species will

undoubtedly be made. Many of these comparisons will deal with questions of substitution (*6, 7*). Should alder be replaced by conifers? Can alder displace traditional hardwoods in certain furniture markets? The answers to these questions depend on a thorough analysis of a variety of technical and economic data on the production system--from growing trees through their end use. What is needed is a framework that incorporates diverse information on the technical, economic, energy, and environmental aspects of the production systems, captures the characteristics that are important to policy decisions, and thus facilitates the study of the role of alder as a source of materials in comparison to competing alternatives (*6*).

The Reference Materials System

During the past 2 years, the National Academy of Sciences' Committee on Renewable Resources for Industrial Materials (CORRIM) adapted the concept of a reference material system (RMS), originally developed at the Brookhaven National Laboratory (*2, 6*) for analysis of materials substitution problems. Specifically, the Committee examined the substitution of renewable for nonrenewable resources. For example, this study developed comparisons among wood, aluminum, and brick as materials for exterior siding.

The reference materials system (RMS) is a network representation of the flow of materials through all production and shipment steps or "activities" required to produce and convert a resource into a form that may be used for a specific purpose.

Figure 1 illustrates an RMS developed by CORRIM for a wood based exterior wall (*2*). At the left side are the resources considered, in this case the forest resource. Along the top are the activities required to transform the resource to the end uses, and along the right side are the end uses, in this case the exterior wall. The activities that may be considered are production or growing, harvesting or extraction, processing, transportation, primary fabrication, installation, erection, maintenance, and recycling. The transportation activity includes the aggregate of all transportation shipments through these various flow stages. A RMS representing the production of a specific product from a specific resource is obtained by tracing a path or trajectory from the raw materials through the activities to the end use. The information contained along this particular trajectory is mass flow in pounds and energy requirement in million BTU. Here the trajectories for converting other resources such as iron ore into nails have already been summarized to a single net figure. Depending on whether the RMS format is to be used as a framework for organizing technical data on labor, capital, raw material, or energy use, the numbers along the trajectory would portray man-hours, cost, value added, energy or material quantity flow. These or other measures of interest can be portrayed as aggregate quantities or as amounts per unit of raw material input or end product output.

In the CORRIM study, detailed trajectories were developed to portray physical material flow, labor man hours use, capital requirement, and proces energy use. In the following discussion, a typical energy trajectory will

RESOURCES	Resource production	Harvest extraction	Processing	Total transportation	Intermediate product identification	Fabrication	Product identification	Additional fabrication	END USES		
									Available Energy	0, −.931	
Forest		684[1], .204[1],		684[1], .432[1]					Medium density fiberboard siding	174, .809	634, 2.337
									Plywood sheathing	110, .378	
									Building paper	15, .038	
									Lumber framing	118, .286	
									Insulation	54, .721	
									Gypsum	208, .284	
										5 , .116	

1/ The mass flow and energy in the harvest and transport columns denote the mass flow and net energy required for harvest and transport of all the materials in the end use

Figure 1.--RMS trajectory summarizing the mass flow (pounds) and process energy requirement (million BTU) for 100 ft^2 of wood based exterior siding.

be used as an example. Feedback or recycling can also be portrayed as shown by the available process energy from residues which can be used to offset the need for outside energy. Initially, trajectories may be developed at a very detailed subsystem level and then aggregated into an overview of the more general system. For instance, more detailed energy trajectories of the harvesting phase may be developed to derive the net energy usage in this activity.

Regardless of the level or kind of detail portrayed, the RMS can be used for analyzing policy alternatives as well as overview displays. For analytical purposes, the RMS is used in conjunction with perturbation analysis. Basically, this involves examining the specific end use in a utilization or substitution problem and defining all new processes and other changes along the affected trajectory. The flows and measures of interest along the trajectory are revised to reflect these changes and the consequences in terms of labor, energy, capital, material, or environmental measures are summarized.

The definition of the technical aspects of new processes must be done outside the RMS which simply captures those characteristics that are important to policy. All too frequently, such technical detail is overlooked in policy analysis because it is not available in a consistent and comprehensive format. A RMS example would be the comparison of wood, aluminum and brick exterior siding.

Table 1 presents data collected by CORRIM on the quantities of the material components and energy used per 100 square feet of construction of a wood-based exterior building wall (2,3). This table is the basis for the entries in figure 1. The energy aspects detailed for each component are fuel used in logging or extraction (col. 2), manufacturing energy (col's. 3 and 4), transportation fuel (col. 5), and energy produced from manufacturing residues (col. 7). The latter category represents production of energy as a by-product of making the exterior wall, whereas the former three categories represent energy consumption. Net energy required or "net energy drain" is the difference between the total energy consumed and the energy produced.

The information provided in table 1 was used to develop the RMS trajectory in figure 1. The ovendry weights of the fabricated components (col. 1 of table 1) have been converted from tons to pounds and are given as the first of each pair of numbers beside each component as listed under Product Identification in the RMS (figure 1). Thus 0.104-ovendry tons of gypsum (table 1) is equivalent to 208 pounds as shown in the RMS (figure 1). The sum of the weights of the components per 100 square feet of construction is 684 pounds. The manufacturing energy value for each fabricated component is the second of each pair of numbers in the RMS (figure 1). For example, the 110 pounds of plywood sheathing used required 0.008 million BTU of manufacturing electrical energy plus 0.370 million BTU of manufacturing heat for a total of 0.378 million BTU.

In the transportation activity, these 684 pounds of components required

Table 1--*Materials and energy use in construction of an exterior wall. (Exterior wall: medium-density fiberboard siding, plywood sheathing, 2x4 frame. Total net energy requirement per 100 square feet of construction1/2/ is 2.541 million BTU)*

Fabricated component	Col. 1 Weight ovendry	Col. 2 Logging fuel	Col. 3 Manufacture Electric	Col. 4 Manufacture Heat	Col. 5 Transport3/ fuel	Col. 6 Gross total	Col. 7 Available mfg. residue energy	Col. 8 Net2/ total
	Tons	- - - - - - - -Million BTU thermal (oil equivalent)- - - - - - - -						
Siding, 1/2 in. MDF @ 42 lb/ft^3	0.087	0.068	0.326	0.483	0.100	0.977	0.238	0.739
Sheathing 3/8 in. plywood	.055	.041	.008	.370	.114	.533	.203	.330
Building paper	.0075	.001	- - -.038- - -		.005	.044	0	.044
Framing, lumber	.059	.056	.046	.240	.116	.458	.490	.172
Insulation (2 in. bats)	.027	.017	- - -.721- - -		.025	.763	0	.763
Gypsum	.104	.015	- - -.284- - -		.068	.367	0	.367
Nails	.0025	.006	- - -.116- - -		.004	.126	0	.126
			.380	1.093				
			1.159					
Total	0.3420	0.204	2.632		0.432	3.268		2.541
Percent (of gross)		6.3	80.5		13.2	100.0		

1/ Horizontal projection of roof structures.

2/ Assumes energy from residuals can be internally used or exchanged in manufacturing phase only (not logging or transport).

3/ Commodity factory to retail yard to house site.

an aggregate of 0.432 million BTU (sum column 5 of table 1). Similarly, logging or extraction to obtain raw materials to produce these 684 pounds of final components took 0.204 million BTU (col. 2 of table 1). In this case, manufacturing activities on raw materials produced residues that were converted to 0.931 million BTU (col. 7 of table 1) of available energy. This "gain" in energy is signified by the dashed back arrow indicating a return to the system. The net energy drain to produce these 684 pounds of components for 100 square feet of wall is obtained by summing the energy consumptions and subtracting energy production:

Million BTU	
0.204	Harvest, extraction
0.432	Transportation
0.809	Medium density fiberboard siding
0.378	Plywood sheathing
0.038	Building paper
0.286	Lumber framing
0.721	Insulation
0.284	Gypsum
0.116	Nails
3.268	Total consumption
-.931	Energy produced from manufacturing residues
2.337	Net

The apparent discrepancy between the net end use energy value shown in the RMS and the net energy value shown in table 1 can be resolved as follows The figure in table 1 is based on the assumption that the energy from residues from these products can only be used internally or exchanged in the manufacturing phase only for this product and could not be channeled to other uses, which is unduly conservative. The RMS trajectory recognizes that this energy could be channeled to other uses. Trajectories for the alternative aluminum and brick exterior walls were similarly derived.

The RMS trajectories include harvesting, transportation, and manufacturing energy up to the construction site. Energy requirements do not include erection because, in general, the energy required for erection is relatively very low. The energy requirements for harvesting and transportation are aggregates for each end use, and pounds of material shown at these steps are total for all materials used in this process. The energy requirements for the manufacturing step under "Fabrication" is disaggregated showing energy required for each material use. Also shown in the RMS diagram is the available energy or residual energy left from the manufacturing process.

From these RMS flows it became apparent that the wood-based construction requires less process energy than the other materials used for construction designs. Although not shown in figure 1, brick walls require 17.35 million BTU, aluminum siding 4.76 million BTU, as compared to 2.34 million BTU required by wood based construction. Thus the brick veneer walls require seven to eight times the process energy of comparable wood

onstruction and those incorporating aluminum about twice that of wood. It ould be pointed out that this comparison examines only the processing ergy to manufacture and produce the designs. There are other obvious facrs to be considered such as maintenance, service life, and energy efficiency in use.

A RMS Example for Alder

To illustrate the application of RMS to alder, preliminary trajectories ave been prepared for the physical flow and labor in producing alder from e forest stand to end use in furniture. In the flow trajectory, only the od component is outlined. We have deliberately left out other ingredients ch as glues, fastenings, finishes, etc.

The physical flow trajectory is shown in figure 2. It starts out with 00 cubic feet of alder raw material in the stand, and this includes bark, ump, tops, and cull material. Loss factors have been applied at each step estimate the quantity of primary product, secondary product, if any, d residue at each process. These loss factors are based on national averge data obtained from CORRIM (*3*), published reports (*1*, *4*, *5*) and estimates f average values obtained from a brief survey of alder manufacturers.

The data for this RMS trajectory for alder are based on limited samling. This is presented for the purpose of demonstrating the utility of is form of analysis in assessing substitution opportunities. For effecive use of this type of analysis, it would be essential to obtain hard data or input to the system. In interpreting this trajectory, we must recognize hat these figures represent estimates of average conditions over all types f products and processing facilities. The dashed vertical line signifies eparation of manufacture commonly performed in the Northwest from manuacture commonly performed in other parts of the country.

If alder is destined to become an important continuing major component f northwest forests, then clearly a sound development is to increase the evel of value added in the region in the processing of the resource. If lder is a transitory species that is not likely to be a significant part of he continuing resource, then substantial investments in processing faciliies will not be attractive and the wood will continue to be wasted or oved in minimally processed form to other regions for conversion to finshed product.

In the Northwest in the typical mature natural alder stand, we estimate hat about 35.2 percent of the stand remains behind as forest residue in the orm of tops, stumps, and cull material. About 34.5 percent of the stand olume is available as pulp logs and chips from manufacturing residue and nother 16.4 percent is in the form of other residues such as bark, sawdust, nd surfacing residue. Only 12.4 percent of the stand enters the furniture ndustry as surfaced dried lumber. These percents do not quite add up to 00 percent. The small difference is the volume loss from shrinkage during rying. It is assumed here that the rough green alder is dried to 9 percent

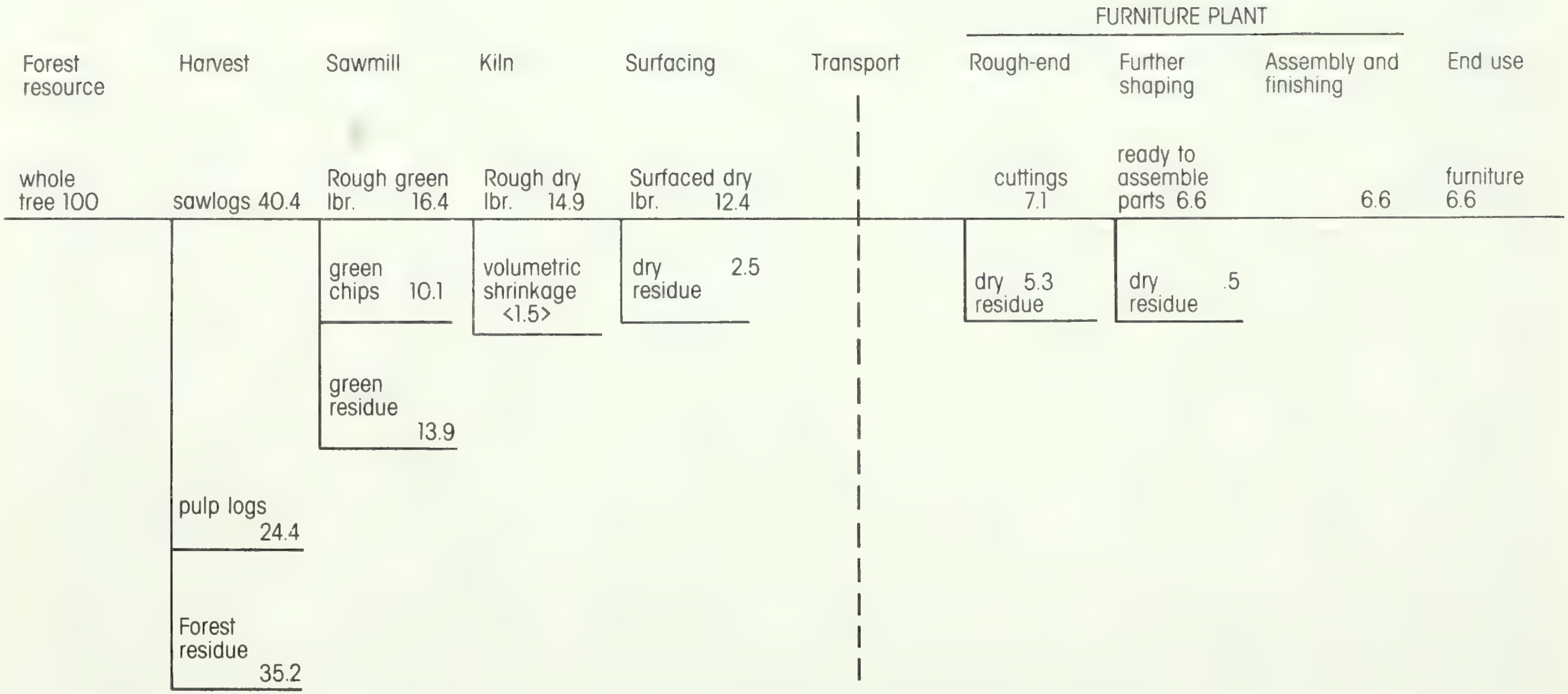

Figure 2.--RMS trajectory showing flow of alder from forest to furniture and use (numbers are cubic volumes).

oisture content. The recovery of dry surfaced lumber is approximately 31 ercent of the log volume on a cubic volume basis.

Of the surfaced dry lumber received by furniture manufacturers, about 3 percent becomes furniture with the remainder developed as various forms f residue (sawdust, chips, particles). The conversion factors assumed for urniture manufacture are 57.5 percent yield in manufacture of cuttings from umber and 92.5 percent yield in converting the cuttings into ready to ssemble furniture parts. The loss in production of cuttings was estimated rom the U.S. Forest Products Laboratory study on dimension yields from lder lumber (*4*) and from discussion with furniture manufacturers, who also uggested a yield range from a low of about 50 percent to about 65 percent, epending on the product line and mix of lumber grades used. The manufac- urers contacted also suggested that about 90-95 percent of the cutting olume becomes finished parts after losses in turning, shaping, etc. In hese cases, we have used the midpoint of these ranges. The trajectory oints out that only 6.6 percent of the volume in the stand is likely to ecome furniture. It also indicates substantial opportunity for residue sing industries.

A second trajectory (fig. 3) was prepared to illustrate the labor in roducing furniture from alder. The values are man hours per cubic foot of aterial produced at each production activity. These figures were derived rom CORRIM data (*3*) and from a brief survey of industry representatives. gain there is considerable variability in labor use depending on product ine, degree of mechanization, etc.; and these numbers should be considered s only rough averages. They are useful however in showing the relative abor use among the various activities. A clearer picture of the labor use s gained when the labor man hours are multiplied by the corresponding uantity of material in figure 2. This information is summarized in able 2.

It is interesting to note the substantial contribution to employment hich alder provides in regions outside the Pacific Northwest. These values ay not be appreciated in the Northwest because they accrue very largely lsewhere. We strongly suspect that a value added trajectory (difference etween gross receipts and factor costs) would be even more strongly biased oward activities in the conversion trajectory that are accomplished largely utside of the Northwest. One reason for this assumption is related to the nput of other materials (glues, hardware, finishes) which greatly enhance he product value and the increasing cost of labor as the material moves rom stump to finished furniture. At the same time, furniture producers in ther regions may have a more difficult time utilizing alder manufacturing esidues which could be readily absorbed in the Northwest. These factors ombined together suggest a case for a vigorous attempt to attract more of he alder furniture industry into the Northwest if alder is viewed as an mportant continuing resource.

There are problems associated with the practice of shipping raw mate- ials long distances to convert to consumer products. Integrated utiliza- ion may be difficult. A region which may be readily suited to the manu-

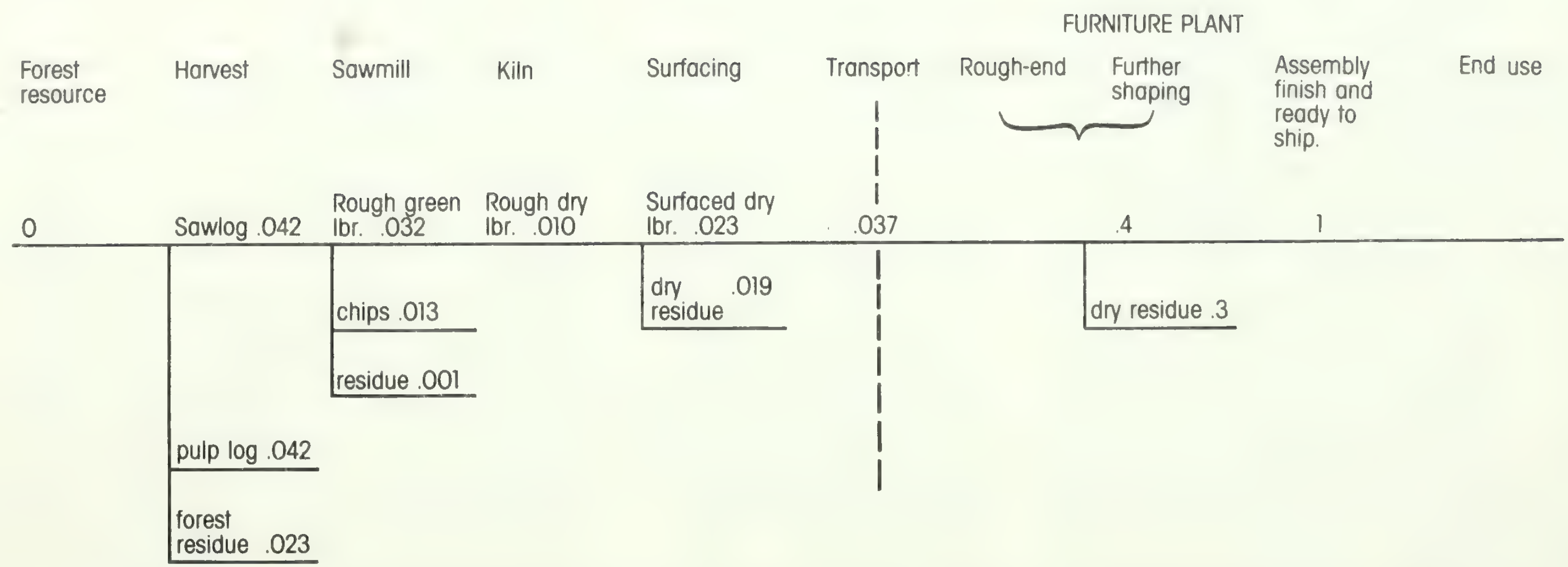

Figure 3.--RMS trajectory showing use of labor from forest to furniture and use (numbers are man hours per ft^3 at each stage).

Table 2--*Summary of labor man hours used in converting 100 cubic feet of alder stand into furniture*

Activity	Man hr/CF	CF	Total man hours	
Forest growing	0	100	0	0
Harvest sawlogs	.042	40.4	1.70	
pulplogs	.042	24.4	1.02	3.53
residue	.023	35.2	.81	
Sawmill R. G. Lumber	.032	16.4	.52	
chips	.013	10.0	.13	
residue	.001	13.9	.01	1.17
Kiln R. D. Lumber	.010	14.9	.15	
Surfacing S.D. Lumber	.025	12.4	.31	
residue	.019	2.5	.05	
Furniture parts for assembly	.4	6.6	2.64	
residue	.3	5.8	1.74	10.98
Assembly, finishing & ready for shipment	1.0	6.6	6.60	
Transport[1/]	.037	12.4 + 6.6	.70	.70
Total of man hours for all activities				16.38

[1/] Logging transportation labor is included in the harvest man hour data.

facture of the primary consumer product may be poorly adapted to the economically feasible conversion of residues. As wood markets improve to the point where whole tree utilization becomes an attractive prospect, there may be great advantages associated with the development of a diverse product conversion complex near the source of the raw material. For example, this could well argue for the growth of a substantial Northwest furniture industry based on alder as a raw material.

The alder utilization trajectory in figure 2 indicates that well over one half (57.4 percent) of the standing volume of stemwood is recovered in a variety of residue forms. At this time, relatively little of this residue is converted to useful consumer products. Growing demand for sources of wood fiber and increased attention to problems of providing viable substitutes for fossil fuels (*7*) suggest that opportunities for integrated utilization of the whole alder tree will be vastly improved in the near future and this could change the climate for the development of an integrated alder conversion system and make alder more attractive as a cultured species.

Finally, one can speculate about the changes in the trajectories if alder became a more deliberately managed species. The trajectories previously illustrated are based upon alder as it occurs in an essentially unmanaged condition. We would expect the following trends if alder production moved from the unmanaged to the managed state:

1. Man hours invested in forest growing would increase.

2. Forest residue would decrease and the fraction of usable roundwood would increase. Control of stocking and improvements in the trees grown as crop trees would increase the yield per tree and also result in fewer culls and small or stunted trees.

3. Perhaps deliberate management can significantly reduce the 35 to 50 years needed to grow merchantable sawlogs in unmanaged natural stands.

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ALDER RESEARCH OUTSIDE THE NORTHWEST: A BRIEF OVERVIEW [1]

JOHN C. GORDON
Department of Forest Science
Oregon State University
Corvallis, Oregon

RICHARD B. HALL
Department of Forestry
Iowa State University
Ames, Iowa

ABSTRACT

Over the past century Europeans have done much cultural and physiological research on Alnus glutinosa. *Black alder has also been studied and used extensively in Europe and the Eastern United States for land reclamation. Most physiological research on black alder has been related to its capability to fix nitrogen symbiotically, although some data on photosynthesis and translocation are available. Other European alder species that have received attention are* Alnus incana *and* Alnus cordata. *The Netherlands, Germany, Sweden, Finland, and Great Britain have alder genetics or tree improvement programs at one or more locations. Most of the cultural studies have had as their objective the increased use of black alder as an intercrop or rotation crop with conifers or poplars. In Great Britain there is renewed research interest in* Alnus rubra, *as a windbreak species for the protection of conifer plantations, and as an amenity tree.*

Introduction

We are fortunate in the Pacific Northwest to have a native, nonlegume itrogen fixer that is fast growing and industrially useful, *Alnus rubra* red alder). Some 13 genera of nonlegume woody angiosperms, encompassing 57 nodulated species, are now reported in the literature. Of these 13 enera, *Alnus* contains the largest number of species (32 out of 35)reported o bear nodules (*3*). Thus, a large reservoir of alder genetic variation is vailable for study and use, and perhaps more important, the possibility xists of great genetic variability in alder endophyte populations. Alders ther than *Alnus rubra* in places other than the Pacific Northwest have reeived considerable research attention in the past and are receiving renewed mphasis.

[1]This is paper 1179 from the For. Res. Lab., Oregon State University, Corvallis, regon 97331.

The purpose of this paper is to give a brief overview of alder research in Western Europe and in North America outside the Pacific Northwest. European black alder, *Alnus glutinosa*, has received the most research attention in these areas. *Alnus incana* (grey alder) and *Alnus cordata* (Italian alder) have also been studied, but considerably less than *Alnus glutinosa*.

Ecology and Physiology

Black alder was the first nonlegume species upon which nodules were observed and reported (*17*), and its forestry potential was recognized early (*4*). Nitrogen fixation by black alder under field conditions was not confirmed until the 1950's (*2*). During that decade, the first broad treatment of the ecology of black alder was published in English (*8, 9*). Thus, intensive study of *Alnus glutinosa* is a recent phenomenon. Other European and Eastern North American alders have received even less attention. Study of black alder as a recent development is surprising because black alder has a vast range and plays an important role in many forest ecosystems. The natural range of *Alnus glutinosa* covers Europe except for the arctic and the Russian steppe (fig. 1). Its Eurasian distribution appears to be limited to areas receiving at least 50 cm of annual precipitation (*8*). Over much of its range, it occurs with *Alnus incana*, with which it is said to hybridize freely.

Black alder is commonly found on stream and lake margins and coastal lowlands, and McVean (*9*) reported that it "cannot regulate transpiration to any great extent by stomatal closure" and that "the alder is not adapted for the invasion of grassland, either directly or after a shrub phase. Neglected grass in which drainage has become interrupted and given rise to seasonal surface wetness is, however, ideal." Akkermans (*1*) recently studied nodulation and nitrogen fixation in fieldgrown *Alnus glutinosa* in the Netherlands. He observed that nodule weight in the field was consistently between 2 and 7 percent of the dry weight of the whole tree and estimated that the mean actual nitrogen-fixing activity in black alder groves probably doesn't exceed 130 kg nitrogen per hectare per year. No comparable figures are available for *Alnus incana* or *Alnus cordata*, but Akkermans' values for *glutinosa* are in rough agreement with those of Zavitkovski and Newton (*18*) for *Alnus rubra*. Mystery surrounds the alder nodule endophyte and its interaction with the host, but recent research (*13*) indicates that the endophyte varies greatly in infective capacity. Little is known about the alder endophyte's life in the soil, and an infective form has yet to be isolated in pure culture, although Lalonde et al. (*7*) have reported the isolation of a noninfective form. Good progress is being made toward understanding the way in which the *Alnus crispa* endophyte enters the host and the way it is nourished inside the nodule.[2] Perhaps the most important physiological studies from a forester's point of view are those relating

[2]M. Lalonde, Kettering Institute, Ohio.

Figure 1.--Occurrence of Alnus glutinosa *(L.) Gaertn. is indicated by the symbol X.*

host tree properties to the effectiveness of nitrogen-fixing activity by the endophyte. The capacity of the host tree to supply photoassimilated carbon to the roots appears to be the principal limitation on fixation rate in nodules (*15, 16*). Recent studies in which the photosynthetic capacity of *Alnus glutinosa* was varied both genetically and environmentally showed that photosynthetic capability was positively correlated with nitrogen-fixing capacity (*6*).

Genetics and Silviculture

Basic genetic information about alders is scarce. The somatic chromosome number of *Alnus glutinosa* has been reported to be 28 or 56; other *Alnus* are reported as having 28, 42, or 56 chromosomes. Again, *Alnus glutinosa* has been the subject of most West European, as well as North American, practical tree-improvement work. Superior trees have been identified, and provenance and breeding work has begun in the Netherlands, Sweden, Finland, and West Germany. Weisgerber (*14*) reported that because of the increasing silvicultural importance of black alder in Germany, seed orchards are being established on the basis of progeny tests. In an initial comparison of progenies from free orchard pollination and controlled pollination, Weisgerber found that those resulting from controlled pollinations were usually superior to free-pollinated progenies.

In the United States, some tree-improvement work has been done on *Alnus glutinosa*. In 1963 the Forest Service established a provenance test of 15 *Alnus glutinosa* seed sources with material collected primarily from Germany. The test was put on a strip mine area in southeastern Ohio where soil pH ranged from 4 to 5. After 7 years of growth, the best trees averaged 20.4 feet in height and 2.7-inch d.b.h. Seed sources from southern Germany performed better than those from northern Germany, Belgium, Denmark, or Sweden (*5*).

The North Carolina Cooperative Hardwood Project has had an active program involving European alder for several years. Several companies are cooperating, but most of the work has been done in Alabama by Gordon White of Champion International.[3] Starting with seedling populations of unknown origin (Illinois Conservation Commission nursery production from Herbst Brothers seed), White now has some plantings 6 years old which have been producing seed for 3 years. He has selected 17 trees from these populations and used them as parents for 120 control-pollinated families which will be set out as a progeny test in 1977.

A new range-wide seed collection for *Alnus glutinosa* has been initiated by R. B. Hall at Iowa State University under the auspices of the NC99 Regional Tree Improvement Project. The objective of this work is to expand significantly the germ plasm base of *Alnus glutinosa* available for selection

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[3] G. White, Champion International, and B. Zobel, North Carolina State, Raleigh, North Carolina, personal communication.

ad breeding programs in the United States. Collections of seed were re-
quested from more than 60 potential European cooperators. Response has been
good. Material has already been received, and the collection should be com-
pleted in the fall of this year for outplanting in 1978 and 1979.

Most silvicultural research on alders has been directed toward their
use as reclamation species or nurse crops, although there is recent interest
n them as components of short-rotation fiber-production systems.

In 1965 the U.S. Forest Service established an intermixture study with
uglans nigra (black walnut) and *Alnus glutinosa* (unknown seed source) on a
bottomland site in south central Illinois. After nine growing seasons, the
alders averaged 35 to 40 feet tall and 5 to 6-inch d.b.h. Maximum size was
2 feet in height and 8.9-inch d.b.h. Unfortunately, at this rate of
growth the alders overtopped the walnut (average height 23 feet) and sup-
pressed their growth. Other conclusions of this study were: 1) On good
sites under management, European alder can produce 3-1/2 tons of dry matter
per acre per year. 2) Dimension stock suitable for furniture manufacture
could be produced on short rotations. 3) The wood-quality characteristics
of pulp from 9-year-old European alder was satisfactory for the manufacture
of printing-grade paper (*11*).

Additional interplanting studies with black walnut and European alder
have confirmed the problem of overtopping. Consideration is now being given
o testing slower growing alder clones for suitability.[4]

In Finland, recent research has shown alder to be adapted to short-ro-
tation culture (*12*), and Mikola (*10*) has described the use of alders in re-
forestation of bogs after removal of peat. In reforestation, pine inter-
planted with alder and fertilized with wood ash were 29 percent taller than
pines planted alone with the same fertilizer treatment.

In Britain, there is renewed interest in *Alnus rubra* (there usually
called Oregon alder) as a windbreak species for protecting conifer planta-
tions, and as an amenity tree. Because it is deep rooting and deciduous, it
is less susceptible to windthrow than Sitka spruce, the most commonly plant-
ed conifer. It is recommended particularly for poorer peat soils. On many
sites in northern Britian, however, red alder is subject to an unexplained
dieback usually occurring after 5-10 years of rapid growth.[5] This dieback
is the principal factor limiting the use of red alder in British silviculture.
Provenance trials and physiological research are now underway in an attempt
to solve the problem.

[4]C. Bey, U.S. Forest Service, Carbondale, Ill., personal communication.

[5]R. Lines, Forestry Commission, Edinburg, Scotland, personal communication.

Conclusion

There is renewed interest in North America and Western Europe in alder research and silviculture. We in the Pacific Northwest can profit from alder research elsewhere. Better coordination among research efforts would speed realization of benefits to be derived from alder culture.

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HARDWOOD CULTURE IN THE EASTERN UNITED STATES

R. L. JOHNSON, Principal Silviculturist
Southern Hardwoods Laboratory
Stoneville, Mississippi

ABSTRACT

Many hardwood plantations are being established in the East. Populus deltoides, Platanus occidentalis, Liquidambar styraciflua, *and* Juglans nigra *are the species that have been planted and studied most.*

Introduction

This paper describes hardwood management in the eastern United States here natural stands account for over 99 percent of the hardwood production. oday, however, between 100,000 and 150,000 acres are in plantations; and he acreage is increasing.

Research on planting of southern hardwoods has been conducted by the orest Service, U.S. Department of Agriculture, at the Southern Hardwoods aboratory at Stoneville, Mississippi, for over 30 years. Initial efforts egan with cottonwood in the 1940's and were greatly accelerated with the dvent of commercial plantations in the 1960's. The Forest Service has two ther units working with intensive plantation culture of hardwoods in the ast. One is at Carbondale, Illinois, where research is being conducted on lack walnut (*Juglans nigra* L.), and the other is at Rhinelander, Wisconsin.

The Trend Toward Plantation Culture

Eastern hardwood forests contain many species and grow on a wide range f sites. The biological diversity among species represents a challenge to ilviculturists whose primary tool in the natural forest is stand manipulation. Evenaged management has been applied to many natural stands during he past 25 years which led, in the 1960's, to clearcutting as the primary ilvicultural system. During the past 5 years, more consideration has been iven to unevenaged management, partly because of public reaction to learcutting.

By creating, through cutting or deadening, conditions that are conducive to the establishment and growth of hardwoods, silviculturists have een able to favor selected species in many different hardwood timber types. For example, forest openings of 1 acre or more usually favor the development

of intolerant species if a seed source is present; smaller openings, particularly those under 1/2 acre, favor tolerant species (*10*).

In southern bottomlands, natural succession and diameter-limit cuts have resulted in many stands of relatively low value on sites of potentially high productivity. Such stands offer few opportunities for manipulation. It is in some of these areas that hardwood culture has been undergoing a slow but significant change to intensively managed plantations during the past 15 years.

A prime example of this change is in the broad bottomlands of the lower Mississippi River. Unlike many areas where eastern hardwoods grow, these sites are well adapted to intensive culture. Terrain is nearly flat and easily negotiated by heavy equipment. Many commercial species grow well including the extremely fast-growing eastern cottonwood (*Populus deltoides* Bartr.); and natural stands are producing much less than their potential.

History of Eastern Hardwood Plantations

Commercial planting of hardwoods began in the South in 1960 when Crown Zellerbach Corporation purchased a 15,000-acre cattle-cotton plantation in the Mississippi Delta. The whole area was planted in cottonwood at the rate of 2 to 3 thousand acres per year. As this was the first large-scale hardwood planting in the South using agronomic-like practices, many problems were encountered. Among the problems were source and care of planting stock quantity and disposition of equipment, spacing, estimates of site quality, and yield predictions. Nevertheless, within 5 years of Crown Zellerbach's original plantings, at least six other companies began commercial planting of cottonwood.

Research and experience have solved many of the problems of planting cottonwood and other hardwoods (methods are similar to those used by farmers in growing corn, soybeans, and cotton). Today, at least two more companies and several private landowners are growing cottonwood and other hardwood species. Other species being planted are black walnut, American sycamore (*Platanus occidentalis* L.), and sweetgum (*Liquidambar styraciflua* L.) which with cottonwood, account for about three-fourths of the total hardwood plantation acreage in the East.

Plantation Establishment

SITE EVALUATION AND PREPARATION

Areas considered for planting are first evaluated for potential productivity. Frequently, identification of soil series is adequate (*2*). Species planted on unsuitable sites have poor survival, slow growth, and are highly susceptible to attack by insects and diseases.

Site preparation is the most costly step in establishing hardwood plan- tions in southern bottomlands. In 1976, contract clearing, raking, wind- wing, burning, and when needed, disking cost about $150 per acre. Such tensive site preparation is required because trees are straddle cultivated til they are about 3 feet tall. Straddle cultivation is essential to hieve nearly complete control of competing vines, weeds, natural sprouts, seedlings.

In the past a number of hardwood plantings have failed because of in- equate weed control, but some species are affected much more than others competition. Cottonwood, for example, cannot tolerate weeds, but yellow- plar (*Liriodendron tulipifera* L.), sycamore, and green ash (*Fraxinus nsylvanica* Marsh.) can often survive and grow above weeds and natural re- neration. None of the hardwoods, however, do well where vines and natural generation combine to compete with the planted trees. There are strong dications that with most intolerant hardwoods, trees that grow well early ntinue to grow better than those that start slowly--another good reason r weed control. Nearly complete weed control is essential for only 1 year cottonwood but for up to 3 years among slower-growing species such as the ks. After trees reach 6 to 8 feet tall, one or two diskings during the owing season are usually adequate to keep plantings growing until crown osure.

Unlike hardwood plantings in the Midsouth, walnut plantations in the ntral States are small, averaging perhaps 8 to 10 acres. Sites are mostly d fields, usually in bottomlands. Weeds are controlled for at least 2 years th chemicals. Most planting and weed control is done by hand rather than th large agricultural-type equipment.

ANTING STOCK

Quality planting stock should be used. Five select cottonwood clones veloped by Stoneville researchers are available for purchase from the rseries of six southern States. On most sites, 20-inch long cuttings are ed when planting cottonwood. For most other species being planted com- rcially, seedlings are used. Best results are from seedlings 3/8 inch or rger in diameter at the rootcollar (*11*). Such seedlings are frequently fficult to obtain from 1-0 stock unless they have been custom grown. rge seedlings are worth additional effort because of better growth and rvival in the field and because they may not require straddle cultivation.

ACING AND YIELDS

Most planters use spacings in the range of 10 by 10 to 12 by 12 feet. ide spacing is preferred because it allows farm equipment to be used for chanical weed control, and it enables most trees to develop into minimum mmercial size, 5.1-inch d.b.h. or larger, without thinning. Wide spacings, wever, may require artificial pruning to produce high-quality sawlogs. rown to total height ratios, which for most species should be 40 or 50 rcent, can be regulated through thinnings. When thinning is delayed too ng, some species such as cottonwood will not respond to the additional

growing space, and growth is below potential. First and even second thinnings can be mechanized by removing alternate rows, but later thinnings are selective.

Merchantable yields from cottonwood plantations have ranged between 3 and 3-1/2 cords per acre per year over 10 years (*6*). Early results with other species indicate that plantation trees grow significantly better than the same species in natural stands.

Recent Work

Sycamore, black walnut, sweetgum, and *Populus* spp. have received the most attention for planting in the East, but current work at Stoneville involves nine other hardwood species, including five oaks. Considerable progress has been made with cottonwood on site selection (*1*), plantation establishment and management (*7*), and insect and disease identification and control (*8*). The most recent work with cottonwood involves 8- to 10-foot tall planting stock to eliminate the need for straddle cultivation, to reduce cost of site preparation, and to establish trees above competing weeds and deer (*9*). Basic work is also being done in nutrient cycling to guide foresters on selection of rotation lengths and the need for species mixtures.

The concept of growing hardwoods at spacings as close as 4 by 6 feet in short rotations (4 to 6 years) followed by whole tree chipping and coppice regeneration is receiving attention. Predicted yields from sycamore grown under this system are high but so are costs (*4*). Initially, the short-rotation, close-spacing work done in the southeast at Athens, Georgia, was for fiber production (*5*). But during the last 2 years, such systems have been envisioned for fuel. At the Forest Service Laboratory in Rhinelander, Wisconsin, hybrid poplars are planted at very close spacings (to 9 by 9 inches), irrigated, and fertilized to achieve maximum yields of fiber in a short time (*3*).

Although planting acreages of eastern cottonwood and black walnut appear to have stablilized, other hardwoods are being more widely planted than in the past. The basic technology for planting most hardwoods is either available or soon will be; the future is in refinements and cost-cutting techniques. Although methods of establishment and management may vary by species and localities, plantations of eastern hardwood species most surely will increase as the demand for hardwood products increases.

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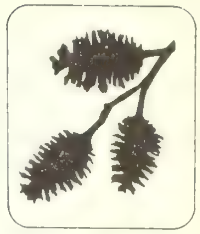
HARVESTING OF RED ALDER



EDWARD T. FEDDERN, Division Forester
Publishers Paper Company
Coastal Division
Tillamook, Oregon

ABSTRACT

The harvesting and marketing of red alder from the Oregon coastal counties requires a company to address itself to several major concerns before entering a major program.

A few of these would be the availability of an efficient contracting force, manpower, harvesting equipment, labor and overhead costs, and the availability of a continuing market. Also, operating seasons in relationship with inventory control, lack of demand for all log grades, sizes and species, capabilities of sawmills to market residuals and adequate log storage facilities.

The management of red alder has given the tree farm manager many logging, arketing, land rehabilitation, and associated challenges. Many of these hallenges or obstacles are interrelated and will be discussed accordingly.

My company, Publishers Paper Co., owns and operates 150,000 acres of rimarily high site land on the northern coastal mountain range of western regon. Of these lands, about one-third of the area supports a combination f native brush types and various age-classes of red alder and bigleaf aple species. Scattered throughout all of these lands, in densities ranging from single trees to small seed blocks, are mixed conifer stands of ouglas-fir, western hemlock, Sitka spruce and western red cedar. Years ago, he original conifer species on most of these lands were either burned or arvested, without any regard for regeneration except for occasional seed trees nd seed blocks. Historically, the creek bottoms and lower wet sites of the oast Ranges had always supported red alder. As time progressed, red alder ncroached onto the burned or logged over areas.

Several years ago, we were faced with the question of whether to manage or red alder or to convert these stands to conifer species. Various organizations have made economic analyses on the feasibility of immediate conversion of alder to conifer species, without regard to age or size of the tand. Some studies favor the retention of red alder to full maturity. ince this will be discussed further in the conference, I will only express he thinking of our Company.

We foresee the ever-increasing problem of guaranteeing a wood supply o conifer species for our own softwood sawmills and paper mills. Presently, we rely heavily on raw material from State, Federal, and private timber sal Due to the every increasing pressures on governmental agencies to increase Roadless and Wilderness Areas, in effect reducing allowable timber cuts and the use of more sophisticated and expensive harvesting techniques because o environmental concerns, the Company felt that having our own lands, with fully-stocked stands of conifer species, will be a necessity 30 to 40 years in the future. This is not to say that we are free of any harvesting restr tions. Restrictions continue to mount on private lands. We felt that we must be less dependent on questionable outside sources for future raw material demands.

Therefore, we have an accelereated alder and brushland conversion program on understocked high site lands to achieve our objectives of fully stocked conifer stands on conifer sites within the next 7 to 10 years. Thi does not mean that we are trying to make red alder an extinct species. On the contrary, when red alder is growing on true alder sites, it is being managed for that species.

Over the past few years, we, as the landowner and timber purchaser, an our logging contractors have continually encountered recurring problems in harvesting and marketing hardwood logs. Ever-present equipment failures an machine and line fatigue occur regardless of the type of harvesting operati and situation. The major concerns in alder harvesting and marketing are th following:

A. a timely road construction program.
B. availability of an efficient contracting force.
C. manpower.
D. harvesting equipment.
E. rising labor and overhead costs.
F. availability of a continuing market.
G. operating seasons in relationship with inventory control.
H. lack of demand for all log grades, sizes, and species.
I. capabilities of sawmills to market residuals.
J. adequate log storage facilities.

The development of a road system in all of our ownership containing stands of red alder is a continuing process. We initiated an ambitious road construction program 2 to 3 years prior to our accelerated alder harvesting program. Since rock sources are plentiful on our ownership in the northern coastal counties, the rocking of all mainline and secondary roads is normally completed one season after subgrade construction. The reason for this is to give the subgrade an opportunity to settle and become firm before the placement of about 40-60 yards of crushed rock per 100-foot station. We are not so fortunate in the central coastal counties of Oregon. Suitable crushing rock is scarce and must be limited to the mainline roads. Logging from secondary roads is usually limited to the drier spring and summer months.

The availability of an efficient contracting force is most difficult, and we have tried numerous operators. Some operators have started in alder logging with a low investment in equipment because of the uncertainty of the venture. Alder logging is not a high volume operation. Loggers can cover only a limited amount of ground in a given day and therefore produce a smaller volume than if they were logging conifers of a similar age and size.

But in order to harvest alder on a large scale, we had to rely on our existing conifer contracting force as a nucleus to build upon. Most of our contractors were equipped to harvest high volumes per acre of mature conifer species, using expensive cable systems.

We tried to convince some of the high producing operators, that generated 10 to 12 loads of conifer sawlogs per day, to shift down to a salvage concept of producing only 4-6 loads of alder per day. This was not done overnight. It has taken several operators and several years to come up with a group of operators who think nothing but red alder salvage logging. Even though a contractor would get the same number of dollars per day that are necessary to cover his daily costs whether he was logging conifer or alder, the idea that alder logging was profitable had to be emphasized time and time again.

It takes a lot of convincing to change a production oriented logger to even think that there may be profit in a hardwood species logging operation. This has been one of the hardest hurdles.

We have not done away with the small operator with a low investment in equipment. He is an important part of the harvest program. Small isolated tracts with below average volumes per acre are best suited for the small operator.

Manpower

The search for manpower for alder harvest operations continues to plague the contractor. Good, experienced timber fallers willing to work in alder stands are very difficult to obtain. The ability of timber fallers to physically traverse steep side slopes that support an overstory of merchantable red alder wih an understory of dense vine maple, salmonberry, and thimbleberry is difficult to measure. Timber fallers take special precautions to provide escape routes away from the specific tree that is being felled. This additional step of slashing or cutting the dense brush is time consuming but extremely important. Also, red alder growing in moderate to steep slopes tend to lean out over the slope. This situation requires additional falling time.

A practice used on large red alder and bigleaf maple is the "boring technique" of falling. After a face cut is made in the downhill side of the tree, a horizontal cut behind the face cut is made through the center of the tree. A narrow block of holding wood is left between the boring and the

face cut for support. The remaining horizontal cut of the back strap releases the tree. This will afford the timber faller an opportunity to minimize "stump pull" and "barber chairing." Also, it is the safest way to fall large, heavy leaners.

The present day direct-drive chain saw also gives the timber faller quicker and greater cutting ability over the gear driven saw. This is primarily a safety advantage in cutting red alder and will also minimize "stump pull."

Red alder, with its characteristic unbalanced crown and outward lean on steep slopes, normally dictates that the tree be felled downhill rather than across the slope. Steepness of slope and density of brush dictate the bucking of the tree into logs. In most cases, it is cheaper to have the landing chaser do the bucking. However, landing size and number of log sorts dictate the feasibility of this method. Limbing is a minimal part of the falling and bucking operation. What small side branches exist on a tree are usually eliminated during the course of yarding.

Rigging crews have similar difficulties in traversing the brushy slopes. The layout of logging turns on cable settings in hardwoods proves to be more time consuming than on conifer settings. The openness of the alder canopy allows more sunlight to reach the forest floor. Thus, brush cover grows more abundantly in alder stands than under the tighter and darker conifer canopy. The density of underbrush and the ability of men to work in and through it must be reflected in ample cost allowances for yarding. Cost allowances for falling, bucking, and yarding cannot be measured solely on the volume per acre of a stand or average yarding distances of a setting.

Another aspect of alder harvesting is the morale factor of woods crews. Historically, being piece-count or loads-per-day oriented, the rigging crew and landing crew has to relate to accomplishment in another way. Most rigging crews will cover 1 to 2 acres per day. Since alder stands on our tree farm range between 2 to 15 thousand board feet per acre, it becomes quite apparent that they cannot base their accomplishment solely on log production. Similar crew sizes operating in fully stocked conifer settings will far exceed their production. A sense of accomplishment is arrived at by knowing that logging is the initial step in reestablishing conifer stands on conifer sites.

Equipment

Regardless of the species harvested, similar techniques of cable yarding and loading are being used. Conventional cable yarding techniques such as ground leading which has minimum available deflection to the partial or fully suspended skyline system, which utilizes deflection principles, are commonly used in alder harvesting. The loggers' ability to ascertain when to use a specific system will maximize their productivity and profit. Also, timely preventative maintenance on equipment will provide less lost time in the long run.

There is an increasing awareness, and rightfully so, that the need to ect soil values and water quality is of vital importance. A minimum round disturbance and log breakage is achieved when the skyline or kline system is used. Higher equipment investments are, however, re- ed to accomplish these objectives. One must note that whatever the em used, it must pay for itself or it becomes economically impractical. , skyline yarding systems, while protecting soil values, do minimal dis- ance to slash and brush concentrations. This in turn increases expend- es in slash disposal and site preparation operations.

Furthermore, regardless of the cable system, the lack of suitable and e stumps for guylining the yarder is common in alder salvage. This is true for placing tail blocks and corner blocks along setting boundaries are established in pure alder stands. Alder stumps, used for these oses, lack the holding power that large conifer stumps afford.

Some form of cable systems are used on 75 percent of our tree farm ations. These systems vary in size, vintage and capabilities. Many investment machines are homemade by ingenious operators. A typical ple of this would be a 50-foot Porta-Spar mounted on a pre-1940 Walters 2-ton truck with a BU50 hoist powered by a Walkashaw gasoline engine. is an extremely slow yarding machine with a line speed of about 500 per minute and poor braking capacity for tight lining capabilities. ime progressed some of our operators upgraded their investments in yard- to machines like the track mounted West Coast Tower. This machine has er line speeds, longer yarding capabilities, and a skyline drum for ining operations.

When possible, tractor and rubber tire skidders complement the cable ation. Utilizing both the tractor and cable yarding techniques on a on landing will reduce logging costs. In the past, tractor and rubber skidding machines were limited to the dry summer months. Since the nt of the wide flat track skidding machine such as the FMC, we have been to expand the non-cable yarding skidding season to the point that ssary cable yarding has been reduced by 10 percent to the present 75 per- . The running surface of this machine applies very little pressure to soil as opposed to the conventional rubber tire skidder. It allows ding during non-rainy winter months where skidders and tractors would be ibited because of no traction. We have found that it does no appreciable nt of soil compaction. This machine is capable of yarding over a layer rush and slash debris, thus minimizing the need for tractor roads. This of machine will climb slopes up to 40 percent, sometimes yarding scat- d volumes that would have been too expensive to log with a cable system. lso has a higher pay load than the conventional rubber tire skidder.

The present hydraulic-type loading machine affords our contractors the ity to load trucks quickly and neatly. An average of 40 to 45 pieces of r per load can be expected. Only through experience can an operator be- proficient in the loading of frequently fast-tapering, irregular-shaped r logs.

Besides the main functions of a harvest program, additional tasks must be concurrently performed to prepare the site for further rehabilitation and to guarantee soil stability and water quality. These secondary, but important, tasks include machine and hand fire trailing, snag cutting, slashing of unmerchantable stems, stream clearance, occasionally complete cull log yarding to the landing site or a partial pull-in of merchantable logs from the perimeter of the setting. These are mentioned as part of the harvesting process because they add significantly to the overall cost of producing the alder log.

Cost

What do these individual operations cost? Cost will be given as an overall average for each job. We have harvested alder from areas that contain single trees per acre to an upper limit of 20 thousand board feet per acre. In nearly all cases, these volumes include varying amounts of scattered conifer species. Our basis for computing compensation to the logger is a combination of what we feel he should produce on a particular operation with the equipment and investment he has available, the length of the average operating season necessary to amortize his investment, the additional tasks to be performed that do not aid in log production and the contractor's labor, equipment repairs, overhead charges, and profit and risk expenses. Keep in mind that in nearly all instances of a salvage program, red alder has more pieces of irregular form, small diameter, higher difficulty in felling, bucking and yarding, and lower volumes per acre than conifer stands of similar age, size and density. Therefore one will experience substantially higher logging costs.

The first phase of the harvest operation is felling and bucking. Average cutting costs in alder are from $10.00 to $15.00 per Mbf. Since an average truck load of alder scales out at 3,500 bd. ft., this cost represents between $35.00 to $52.50 per load. Converted to a weight basis--the cost is $0.67 to $1.00 per thousand pounds. The average cutter today is seeking between $90.00 to $100.00 per day. This pays his wages for 6 hours cutting, transportation to and from the job, and saw costs. A timber faller will average from 10 to 14 Mbf per day of felling and bucking.

Because of the complexity of yarding due to the numerous types of yarding techniques and numerous obstacles encountered (streams, buffer strips, long reaches, and required log suspension) costs vary greatly and can only be discussed as an average. The basic yarding crew is four men. This includes the yarder operator, chaser, and two rigging men. Labor costs for this work force, including overhead and transportation, amount to $400.00 per day.

Overhead charges for labor, which have risen sharply, add costs to the operation. Take, for example, State accident insurance rates for Oregon. From July, 1975 to July, 1977 these rates have gone from $22.22 per $100.00 of wages to $35.00 per $100.00 of wages, or an increase of 58 percent in 2 years This cost alone has increased the harvest cost an additional $5.00/Mbf.

With labor costs and the high cost of yarding equipment that must be aortized and maintained, one can quickly see that a high volume of production is necessary in order to achieve an average cost of $28.00 to $32.00 pr Mbf or $1.88 to $2.15 per thousand pounds for the yarding phase. It ecomes necessary to utilize the cheaper tractor yarding technique whenever ossible to maintain cost control because of the necessity of cable yarding ost of the area.

Loading costs average between $12.00 and $16.00 per Mbf or $0.81 to $1.08 per thousand pounds.

Advanced decking of logs from low volume yarding areas without immediate oadout will make loading equipment available for the higher producing adjcent settings. When cull yarding or stream clearance tasks must be accomplished on the logging side where the loader was working, the operator can shift his loader to the predecked wood. This helps maintain an even flow of logs to the market and allows cost control of the loading phase.

The additional tasks that are concurrently performed during the harvest ontinue to increase in cost. Snag cutting, fire trailing, stream clearance, nd cull log yarding are all done to varying degrees on any particular operation. An overall realistic average cost for these tasks increases log harvesting $8.00 to $12.00 per Mbf or $0.54 to $0.81 per thousand pounds.

A summary of all harvesting costs reflects a range of $58.00 to $75.00 per Mbf f.o.b. truck. Converted to a weight basis, this amounts to $3.90 to $5.04 per thousand pounds.

Present trucking rates demand about $27.00 per hour. Based on a 9-hour ay, the average log truck is able to haul three loads of alder per day. his total cost of $240.00 per day hauling 10.5 Mbf converts to $22.85 per bf or $1.54 per thousand pounds.

To summarize, these costs represent a range that the large majority of alvage operations will fall within. These costs do not reflect the company's dministrative costs, stumpage rates, or road construction costs. They do epresent costs experienced not only from company land operations but also rom government alder conversion timber sales. Therefore, the range of logging and trucking costs is between $80.00 to $100.00 per Mbf or $5.44 to 6.58 per thousand pounds. One can see that these costs, when added to tumpage and administrative costs, will frequently exceed log market values. ising costs of labor and equipment make it paramount for the logging industry to find more efficient ways of harvesting alder. However, the alder ndustry must also recognize these rising costs and do their part in allowing igher log values at the market place.

Another main concern is the availability of a continuing hardwood market. dequate communication between buyer and seller about forthcoming market delines will minimize the amounts of felled and bucked red alder logs. As veryone knows, cut alder will decay rapidly if left in the woods, especially f felled during the sap flow period.

An adequate well rocked road system will allow flexibility in the landowner's harvest program by lengthening the operating season on his lands.

In recent years, government agencies have increased the sale of red alder in their efforts to convert alder stands to conifer species. The relatively short operating season, normally from June to October on many alder timber sales, has a log saturation effect on the market. This has forced change of some logging programs to the "off" season in order to maintain an even flow of logs to the market place.

Another problem of a large scale alder harvesting and conversion program is that all sizes and grades of alder are produced. Since the sawmill desires the higher diameters of alder sawlogs, the landowner is left with the low grade and pulp type logs for which he must find a suitable outlet. We have been fortunate in disposing of the smaller logs to a local plug mill. But as we accelerated the alder harvest, it became apparent that this one outlet within the economical haul distance could not absorb the high anticipated volume of smaller logs. At about this same time, alder lumber demands increased. Local sawmills started second shifts, thus requiring more wood. We could generate the sawlog volume to help satisfy their needs but in so doing, generated proportionally more small logs. To high-grade an alder stand, leaving the low grade and pulp logs, would not only be poor utilization and waste dollars, but would increase a slash debris problem. We reached an agreement that all outlets would be treated equally. Each sawmill, plug plant, or veneer plant would take camp run logs, which included logs down to a 5- to 6-inch top. This wood was sold to them on a per ton basis. We try to merchandize wood down to a 30-board-foot log size. This program has provided a wood supply to all outlets and has allowed us to continue our program.

Furthermore, as the demands for red alder increased, so have available supplies. Some government agencies also require the removal of the lower grades and pulp logs on alder conversion timber sales. The general size for merchantability is that No. 4 grade or 6-in-diameter logs be removed down to a volume of 10 bd. ft. This low merchantability standard of 10 bd. ft. per piece means that a 6-in log 8 foot long must be harvested. This type of utilization, along with stumpage rates of $40.00 to $50.00 per Mbf on No. 3 grade logs, only compounds the overall harvesting problems. In most instances, these stumpage rates are established by the various governmental agencies using their standard appraisal systems. Due to the rising logging and trucking rates, which are not truly reflected in the appraisals, it becomes necessary to subsidize contractors in other ways in order to show a breakeven point on alder harvest.

The lack of industry demand for bigleaf maple adds concern. Many of our ownership blocks have an abundance of bigleaf maple growing in association with red alder. This must be logged along with red alder in order to allow an operation to be economically feasible.

Capabilities of alder sawmills, plug mills, and veneer plants to market sawdust and chips have an effect on all sizes and grades of logs. Here

in, the buyer and seller must communicate in order to limit deliveries ing times of soft residual markets.

The need of all manufacturing plants to provide ample storage facilities logs is a continual problem. Buyers of alder must keep in mind that the ducer cannot always deliver raw material as originally agreed. Due to ther and road condition changes, fluctuations in the softwood market, and ber sale restrictions, the supply of wood may lag behind a schedule or e faster than what the buyer wants. As alder sawmills take advantage of d markets by adding second shifts, they must recognize the need to expand d facilities to handle adequate log supplies.

Finally, one of our concerns in the alder conversion program is public nion. The private sector that lives, works, and recreates in and around vesting activities must be informed as to reasons why certain management hniques are being used. Many times they will not agree with a specific ctice, but it is our responsibility to communicate and express our view nt. We are in an age that the public demands that we manage our resources ely so that demands for the future will be met.

ALDER CHARACTERISTICS AS THEY AFFECT UTILIZATION

TOBY ATTERBURY, Assistant Supervisor, Forest Inventory
Northwest Timber Division
Crown Zellerbach Corporation
Portland, Oregon

ABSTRACT

The utilization of red alder in the Pacific Northwest is tied to its location, yield, tree size, and wood properties. Up to the present time, conifers have been utilized and managed because they are more profitable. When the older stands of large conifers are harvested, alder may become fully utilized on its own merits.

Alder (*Alnus rubra*) is the most important and the only significant hardwood in the Pacific Northwest. It ranges from central California to Alaska, with the best commercial stands being in the middle of the range (fig. 1).

Alder has been considered a weed and a problem by many forest land owners. This conference may mark a turning point in our attitude and management of this species--I hope so. Recent surveys of the Pacific Northwest have revealed increasing acreages and volumes of alder. In many cases this difference is due to better stand classification. Many previous surveys and forest inventories classified young alder as brush. Recognition may be an indication of better times ahead for alder.

Forest land managers in past years have tried many management techniques for alder lands which have included:

ignoring it,
destroying it by spraying, smashing, and "hack and squirt," and
harvesting, selling, and/or utilizing the logs, followed by attempts at conversion to conifers.

Usually these activities have cost the landowner or logger money. So we have a problem in utilization. Why? What characteristics of alder have created this problem?

Alder has several characteristics which have an effect on utilization:

location (a hardwood in a softwood economy),
prolific seeder, preferring good sites,
growth patterns and yields,
tree and log size, and
wood properties and grade.

Figure 1.--Natural range of red alder (Alnus rubra).

A HARDWOOD IN A SOFTWOOD ECONOMY

Historically, the forest industry is geared for softwoods in the Pacific Northwest. The mills, logging equipment, land management techniques, and forestry education have been Douglas-fir oriented. Red alder finds itself in one of the largest conifer producing areas in the world.

The hardwood industry in the Northwest is small and struggling. Some pulp mills buy alder logs for chips. Alder sawmills are small and scattered about the region. Generally they are owned by private individuals with no land holdings. Alder logs are purchased from loggers or landowners, and often come from conifer clearcuts or farm lots. Products are sold to jobbers. Consequently, it is not uncommon for alder mills to open and close frequently, depending on log supply and orders for the products.

The demand for alder logs is far below the potential supply. This surplus in supply has created a rather low value for the logs. Comparisons of red alder characteristics in yields, grades and values with those of Douglas-fir and western hemlock are necessary in our current economic situation. All of the comparisons made in this paper are made from normal yield table data site index 140, site III, base 100. On base 50, this is slightly less than site index 90.

PROLIFIC SEEDER, PREFERRING BEST SITES

Alder is a prolific seeder, starting at young ages. Seed will carry for long distances. High site land that is clearcut and burned can and will seed in with alder if standing trees are within range. Many of the alder stands which exist today were started in the 1920's through 1940's from clearcutting and burning.

During this period, alder was not utilized except as fuelwood. Alder trees were either left, knocked down, or burned. Alder stands tend to be found in the damp, fertile creek bottoms, the best growing sites. These are also the most fire resistant sites. Consequently, alder seed sources are nearly always available. Thus, alder stands are very common in the higher site coastal and valley areas in the 30- to 50-year-age range. This will make up a rather large share of the wood supply in the next decade or two.

Industrial and private ownerships, which have contributed the lion's share of the forest products to date, also contain a high proportion of alder. Figure 2 illustrates the higher percentage of alder in private ownership. This is also the higher site land. Red alder only grows to elevations of 2,500 feet.

GROWTH AND YIELD

Alder is often referred to as a fast growing species. This is true in some respects and not true in others. Growth is a rather gross term, and must be specified to be meaningful. Height growth of young alder is very

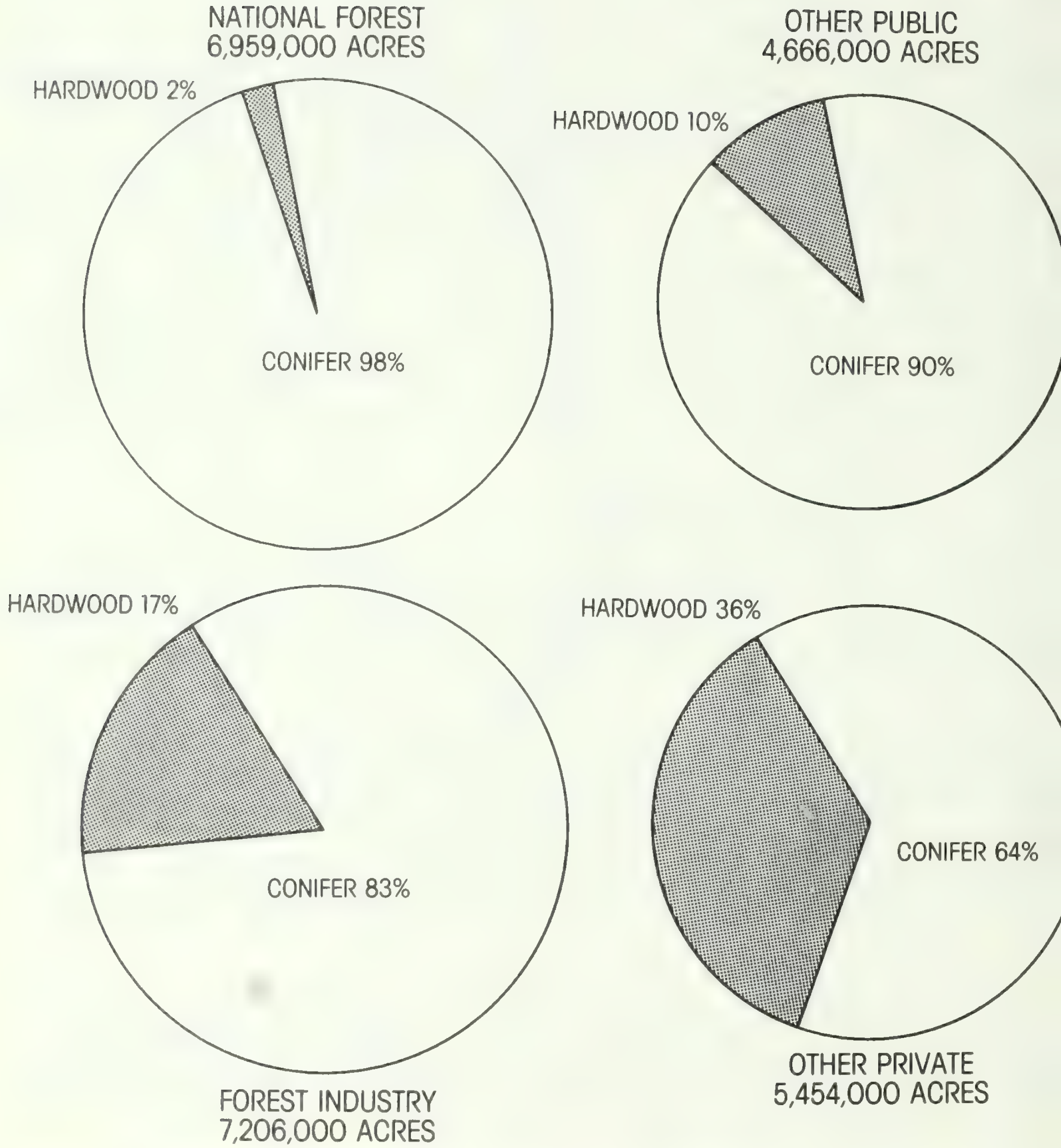


Figure 2.--Acreage distribution of alder and conifer by ownership catego
Western Oregon and Western Washington.

apid. Compared to the conifers (fig. 3) alder produces the tallest trees or the first 30 to 40 years. Many of you have probably observed alder rowing 5 to 10 feet high on a new road cut in the first growing season. lantations of Douglas-fir are often invaded by natural alder seeding which ust be sprayed or it will quickly overtop the fir. Why, you may ask, do we pray the alder when it will outgrow the fir? The answer is volume. Figure plots the gross cubic volume of the three species over a 60-year period. lder does outproduce the conifers for the first 18 or 20 years; however, at ge 60, a common rotation length, western hemlock volumes more than double hose of alder. Short rotations may be an answer.

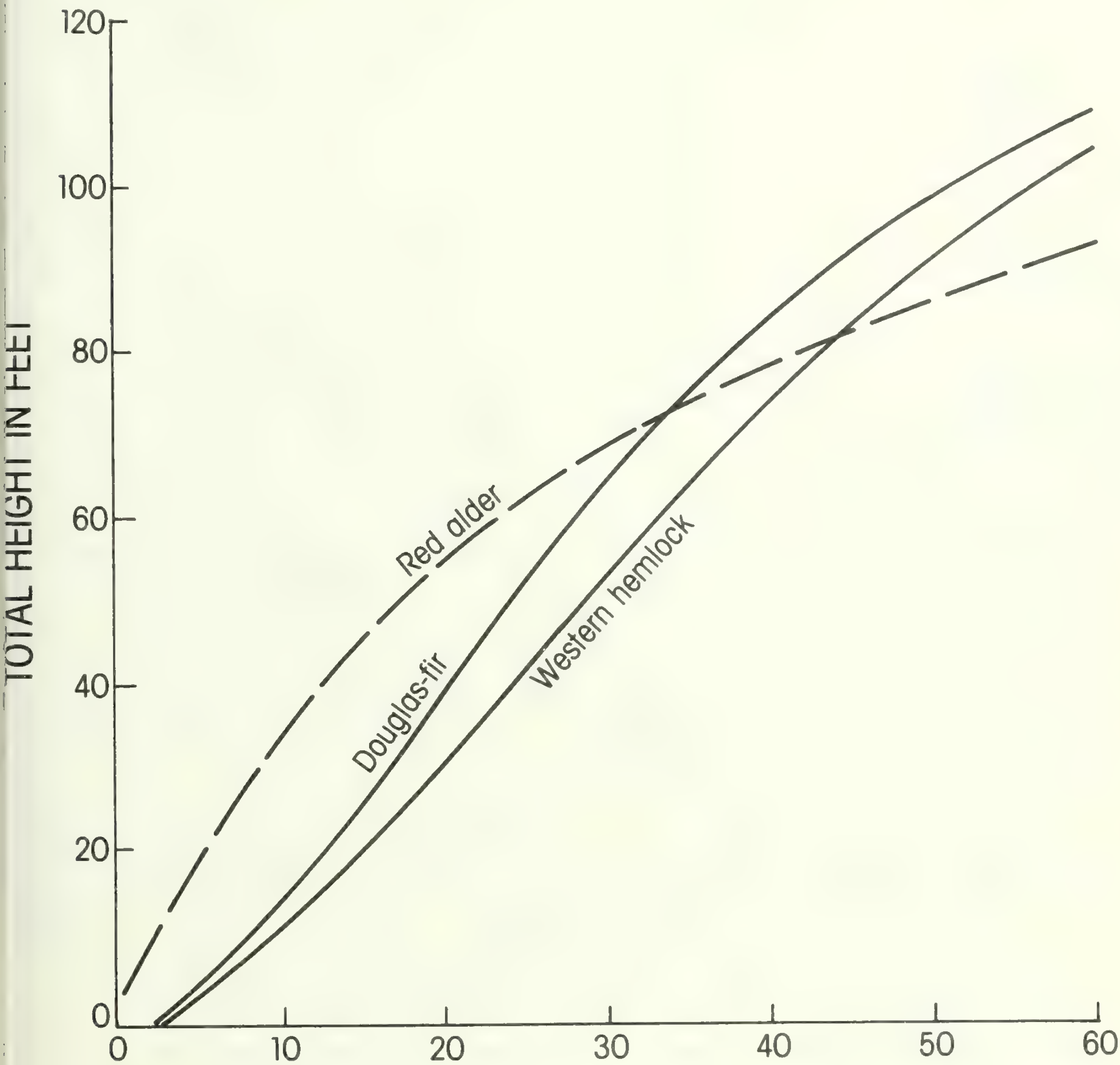


Figure 3.--Comparison of dominant and co-dominant height between Western hemlock, Douglas-fir, and red alder. Normal yield tables at site index 140.

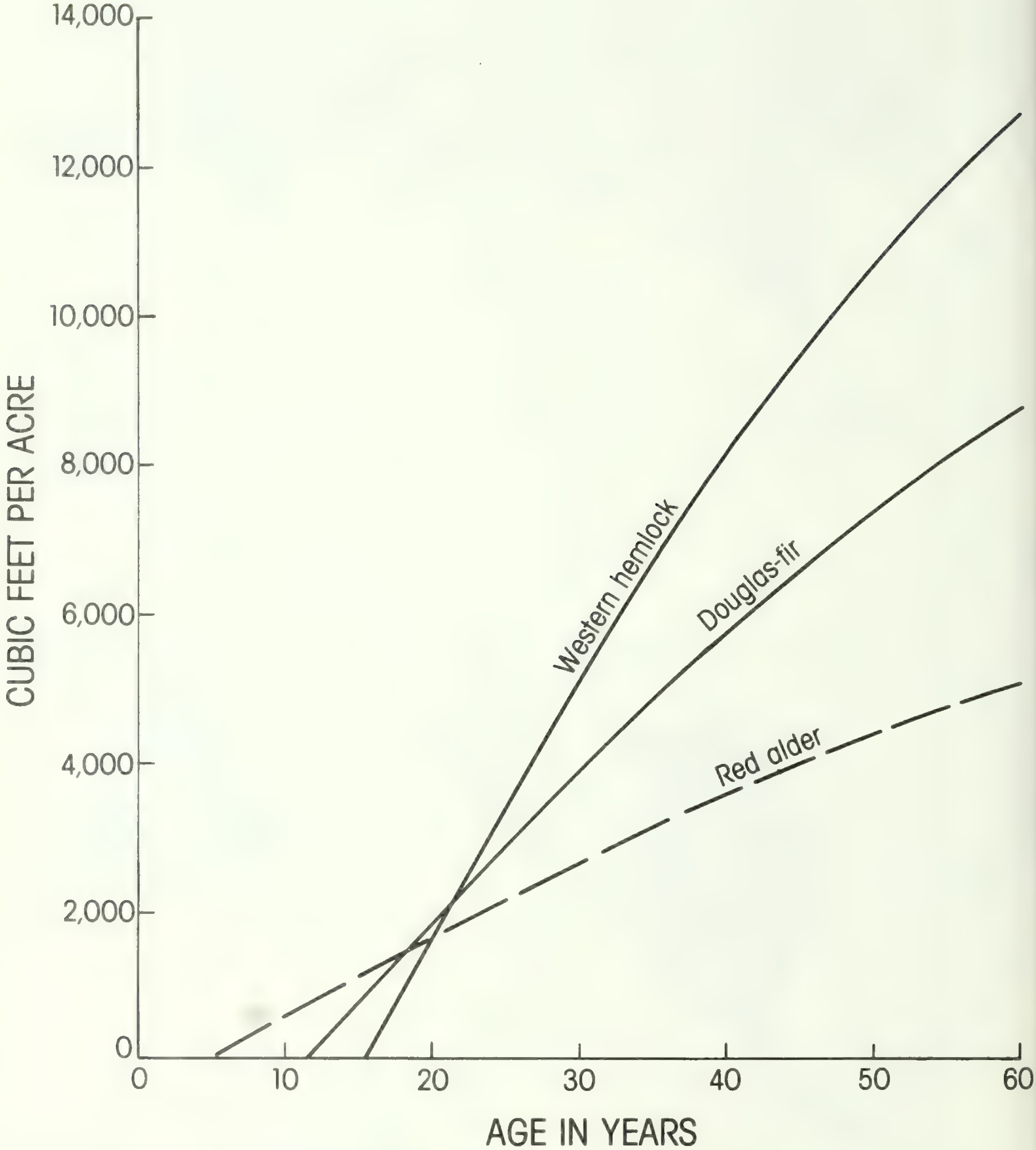


Figure 4.--Yield comparison of Western hemlock, Douglas-fir, and red alder. Normal yield tables at site index 140.

REE AND LOG SIZE

Alder stands generally start with many thousands of trees per acre. ithout management, which is the case for almost all alder stands, the trees ompete for survival, resulting in slow diameter growth and high tree ortality. Consequently, the typical 40-year-old stand today has a small verage diameter, usually about 10 inches. This results in a small tree and og size. Figure 5, however, shows that average tree volume for normal tands of alder is not much different than for conifers in the 60-year rotaion. Red alder trees are actually larger than the conifers during the irst 40 years.

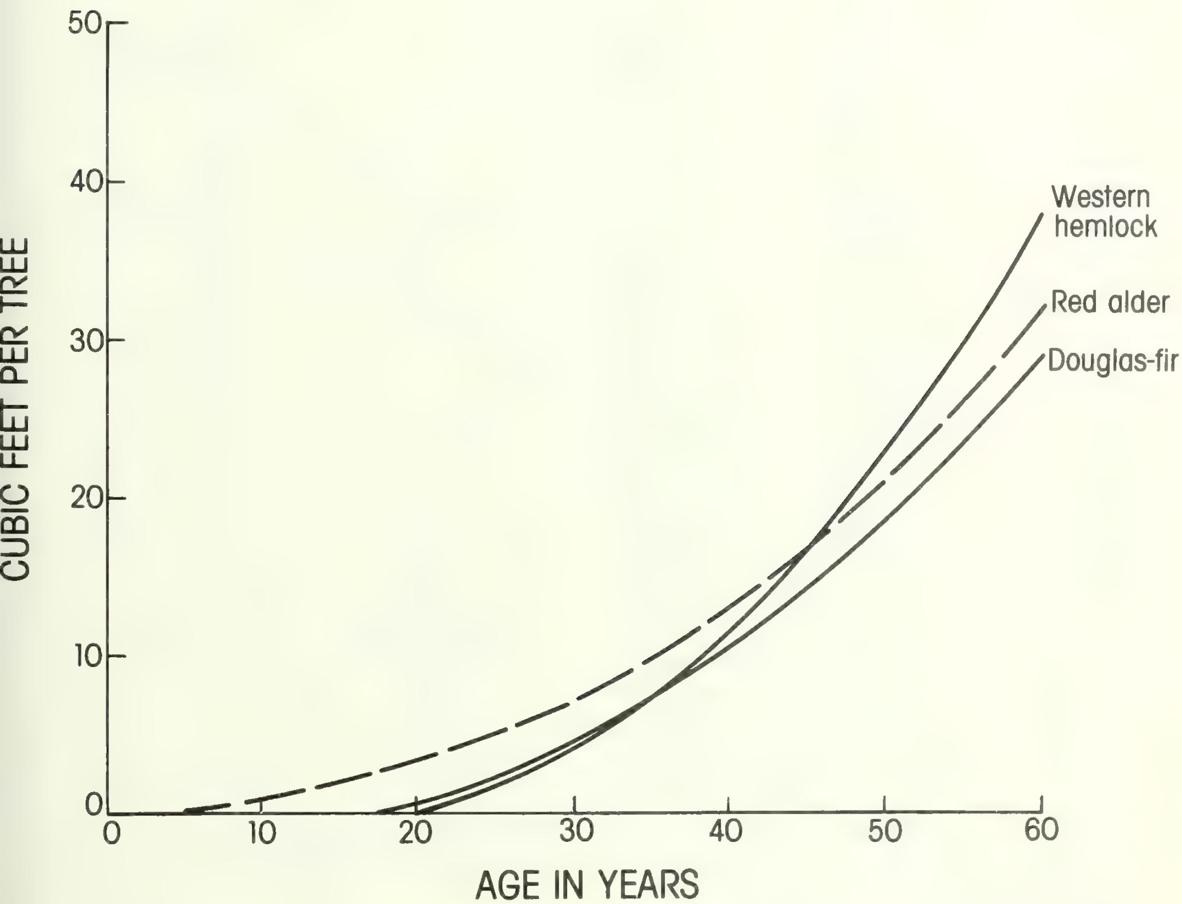


Figure 5.--Cubic feet per tree over age by species for normal yield table stands at site index 140.

The utilization of alder has not been complete partly due to size and age. Alder, being a short-lived species, rarely attains the age of 100 years. Conifers live much longer, allowing the individual trees to grow much larger. These older conifer stands still exist on many ownerships. Naturally, loggers will take the easiest, most valuable, and best trees first. Figure 6 illustrates that the cost of production increases as log size decreases. Conversely, value increases as log size increases. Our logging equipment is designed for the larger, more valuable conifer stands. Log handling and storage facilities are also designed for the larger wood. This, coupled with the fact that alder does not store well in cold decks for long periods, has kept most large landowners out of alder production.

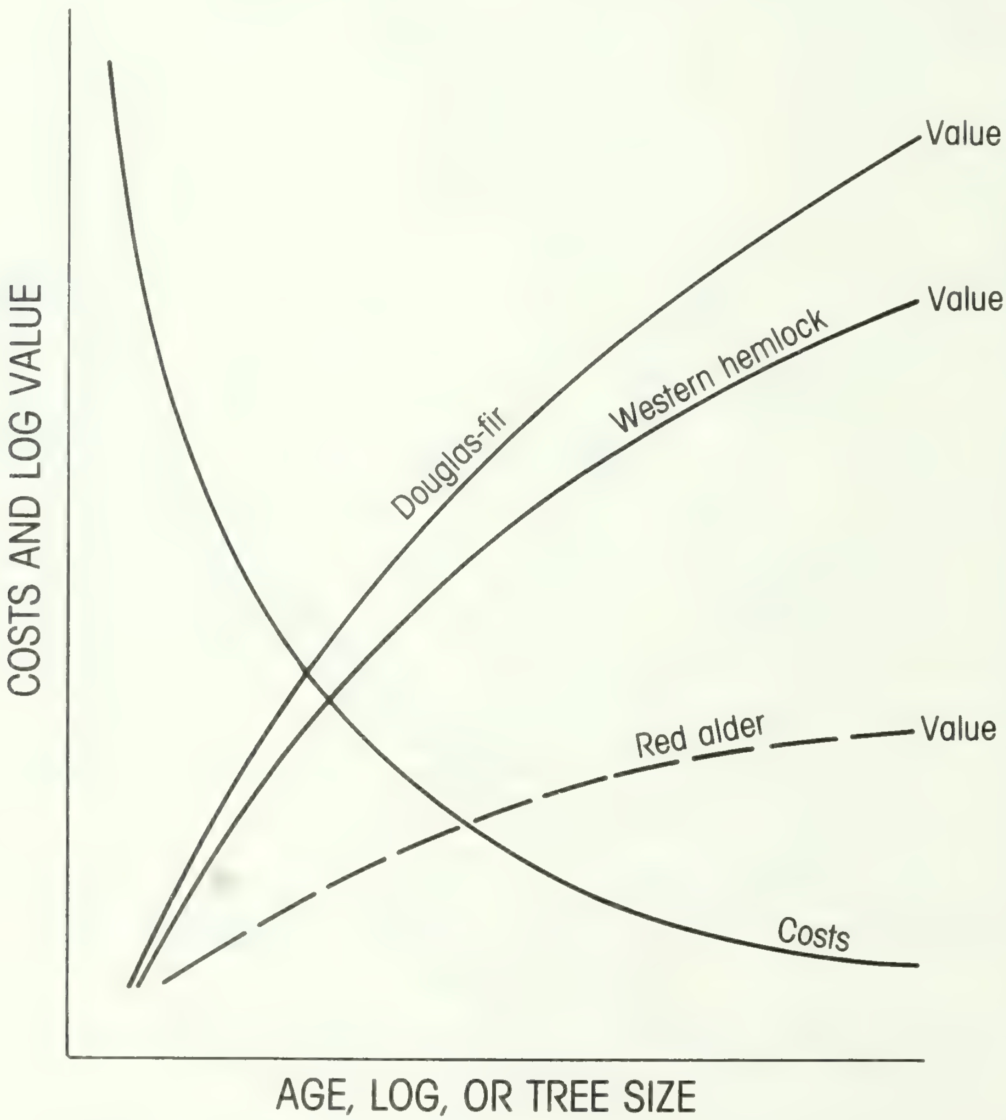


Figure 6.--Production costs vs. sales realization (price) over age, log, or tree size for Douglas-fir, Western hemlock, red alder.

High production cost and low unit values have made alder a poor per-
ormer in realization per acre. Figure 7 compares the three species in gross ealization per acre on our site index 140 example. The conifer yield in ollars is two to three times that of alder.

Figure 7.--Gross realization per acre by species for normal stands at age 60--site index 140.

WOOD PROPERTIES

Everyting I have discussed to this point has favored the conifers. Growth, yield, size, and value have created a favorable situation for the conifers.

Alder, of course, does not compete in the same marketplace as the conifers. To date, it has been used as pulpwood and as a substitute for other

hardwoods. Alder is being used in furniture, cabinets, novelties, trim, paneling, pallets, and plugs for paper rolls. The wood is easy to work, stains and paints nicely, and has a pleasing natural color of light yellowish brown when dry. It has a fine, uniform grain, and smooth texture. It has good nail and tack holding abilities with little tendency toward splitting. Green alder logs and lumber decay rapidly. The logs must be manufactured soon after cutting, and the lumber must be kiln dried. Alder has its own set of log grades, published by the Log Scaling and Grading Bureaus. These grades give the scaling diameters and the amount of high grade lumber that can be produced from a log.

Let's take a look at a typical red alder tree in a 40-year-old well-stocked stand. This tree has 12-in d.b.h. and is 80 feet tall. If we bucked two 32-ft logs we would net 18 ft^3, 13 in the first log and 5 in the second. This means 72 percent of the volume is in the butt log. This typical alder tree probably has no limbs or knots in the first 32-ft log. Even though alder trees are small and produce low volumes per acre compared with the conifers, they will produce a high percentage of clear wood. Conifers grown on a rotation of 40 to 60 years will produce little clear wood. Alder does. Will clear, knot-free boards and panels be worth anything in the future? I believe they will. This ability to produce clear wood plus nitrogen-fixing ability, in a future with an energy-short world, may make alder utilization a reality.

Conclusion

I sincerely hope this conference brings an awareness to our industry that this region has nearly 16 percent of the forest land base in alder which must be utilized and converted to useful products. Red alder in the Northwest is more abundant than the current demand. Log production has been geared for the larger, more valuable conifers. Utilizing alder stands has consequently been slow. The relatively low gross realization of alder compared to conifer may change as the age of the conifers is cut back to that of alder.

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BUYER'S PERSPECTIVE ON PUBLIC AGENCY TIMBER SALE PROCEDURES FOR ALDER

PAUL BARBER, President
Paul Barber Hardwoods
Philomath, Oregon

MARVIN NOBLE, President
Noble & Bittner Plug Co.
Hebo, Oregon

JUEL SHELDON, Raw Material Manager
Ross-Simons Hardwood
Longview, Washington

ABSTRACT OF PANEL DISCUSSION

Experiences of the hardwood industry in buying alder from public land management agencies have not often been favorable. A wide variety of log selling procedures are found among the various agencies in the Pacific Northwest but there are common problems from the standpoint of the hardwood buyers. One such problem is related to the mix of species included in hardwood sales. A sizable volume of conifer timber is often included in the sale. This timber is difficult for the hardwood operator to market. The conifer component attracts bids from the conifer industry making it difficult for the hardwood industry to compete. Separated sales of hardwood and conifer would increase bidding by hardwood operators and improve utilization of hardwoods, which are often poorly utilized by conifer operators.

The second major concern about hardwood sales is the lack of accurate timber volume estimates. Operators have found that cruises on alder stumpage have cut out from 36-131 percent. This degree of uncertainty is a significant factor of concern for anyone attempting to bid on alder. Agency and hardwood industry personnel should work together to attain a higher degree of cruising accuracy.

Timber sale procedures and agency attitudes toward hardwoods vary tremendously. Agencies must recognize the unique features of hardwood stands as well as the needs of hardwood operators in order to develop procedures that are more conducive to active bidding by the hardwood industry.

A COMPARISON OF LUMBER GRADING RULES FOR ALDER AND COMPETING SPECIES

CALVIN G. FYE, Manager-Quality Assurance
Northwest Hardwoods Inc.
Arlington, Washington

DAVID G. BRIGGS, Assistant to the Dean
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

This paper contains a comparison of lumber grading rules and practices for red alder and competing species in the hardwood lumber trade such as birch, yellow poplar, soft maple, and black cherry.

Introduction

Grading rules are the specifications used to define the quality of umber. When logs are converted into lumber, they yield boards which vary n size and in the type and location of defects. Grading, in which lumber s segregated into use - oriented categories with an appropriate quality ange, permits a user to buy the quality that best suits his purpose. The bjective of grading rules is to classify and place on the market lumber of tandard sizes, shapes, and qualities, irrespective of the varying conditions f manufacture and the kind and size of logs that produced it. For strucural uses, strength is desirable; and hence the direction and width of the rowth rings and the size, number, and location of knots are important. For oors, sash, furniture and similar items, boards that have clear or clean aces are desired.

The grade of a piece of lumber is based on the number, character, and ocation of features that may lower its strength, durability, or utility alue. Among the common visual features are knots, checks, pitch pockets, hake, and stain. Some grades must be free or practically free of these eatures while other grades allow fairly numerous knots and other features ithin specified limits.

Hardwood lumber is graded according to three basic marketing categories factory lumber, dimension stock, and finished market products. Hardwood factory lumber is similar to softwood factory and shop lumber in that it is graded on the basis of the percentage of the board area that will yield clear or sound cuttings of specified sizes. Grade is based on the quantity of usable wood in the piece rather than on the size, type, or location of defects. Hardwood lumber is usually graded from the poorest face in the rough green condition; that is, before kiln drying and surfacing.

Hardwood dimension stock is manufactured to the specific size and grade requirements of the end product. Both factory lumber and dimension stock are intended to serve industrial consumers. Finished market products are graded for unique end uses requiring little or no remanufacture (an example is hardwood flooring).

This paper concentrates on the grading of the hardwood factory lumber. Rules used in grading hardwood factory lumber are issued by the National Hardwood Lumber Association (*1*). Figure 1 summarizes the standard grades which are applied to most species. In practice, the first two grades, Firs and Seconds, are combined into a single grade "firsts and seconds" (FAS). Figure 1 indicates that, in addition to the minimum percent yield requirement, the grading rules contain stipulations as to minimum board dimension, minimum cutting size, and the number of cuttings that can comprise the yiel For example, the highest grade of hardwood lumber is called "firsts" which requires that at least 91-2/3 percent of the board be in clear-face cutting Boards in this grade must be at least 6 inches wide and must be 8 to 16 fee long. As can be seen in figure 1, the actual FAS percent yield requirement varies according to the surface measure of the board and the number of cuttings that are allowed. The cuttings must also meet a minimum size requirement of 4 inches by 5 feet or 3 inches by 7 feet.

Information in figure 1 consists of basic grade descriptions. The reader should refer to the National Hardwood Lumber Association (NHLA) rule book (*1*) for more detail and for deviations associated with individual species. The grading rules for Pacific coast red alder summarized in figure differ from the standard hardwood grades. These alder rules are described in detail on pages 45-46 of the rule book (*1*). For example, the highest alder grade is "Select and Better," which requires at least 83-1/3 percent yield in clear-face cuttings from boards at least 4 inches by 4 feet in siz This yield can be obtained in an unlimited number of cuttings, but the minimum cutting must be a least 4 inches by 3 feet or 3 inches by 6 feet.

Figure 1.—Standard hardwood cutting grades[1]

Grade and lengths allowed (feet)	Widths allowed	Surface measure of pieces	Amount of each piece that must work into clear-face cuttings	Maximum cuttings allowed	Minimum size of cuttings required
	In.	*Sq. ft.*	*Pct.*	*Number*	
irsts:[2] 8 to 16 (will admit 30 percent of 8- to 11-foot, ½ of which may be 8- and 9-foot.)	6+	4 to 9	91 ⅔	1	4 inches by 5 feet, or 3 inches by 7 feet
		10 to 14	91 ⅔	2	
		15+	91 ⅔	3	
econds:[3] 8 to 16 (will admit 30 percent of 8- to 11-foot, ½ of which may be 8- and 9-foot).	6+	4 and 5	83 ⅓	1	Do.
		6 and 7	83 ⅓	1	
		6 and 7	91 ⅔	2	
		8 to 11	83 ⅓	2	
		8 to 11	91 ⅔	3	
		12 to 15	83 ½	3	
		12 to 15	91 ⅔	4	
		16+	83 ⅓	4	
elects: 6 to 16 (will admit 30 percent of 6- to 11-foot, ⅙ of which may be 6- and 7-foot).	4+	2 and 3	91⅔	1	Do.
		4+	(3)		
Io. 1 Common: 4 to 16 (will admit 10 percent of 4- to 7-foot, ½ of which may be 4- and 5-foot).	3+	1	100	0	4 inches by 2 feet, or 3 inches by 3 feet
		2	75	1	
		3 and 4	66 ⅔	1	
		3 and 4	75	2	
		5 to 7	66 ⅔	2	
		5 to 7	75	3	
		8 to 10	66 ⅔	3	
		11 to 13	66 ⅔	4	
		14+	66 ⅔	5	
No. 2 Common: 4 to 16 (will admit 30 percent of 4- to 7-foot, ⅓ of which may be 4- and 5-foot).	3+	1	66 ⅔	1	3 inches by 2 feet
		2 and 3	50	1	
		2 and 3	66 ⅔	2	
		4 and 5	50	2	
		4 and 5	66 ⅔	3	
		6 and 7	50	3	
		6 and 7	66 ⅔	4	
		8 and 9	50	4	
		10 and 11	50	5	
		12 and 13	50	6	
		14+	50	7	
No. 3A Common: 4 to 16 (will admit 50 percent of 4- to 7-foot, ½ of which may be 4- and 5-foot).	3+	1+	[4] 33 ⅓	(5)	Do.
No. 3B Common: 4 to 16 (will admit 50 percent of 4- to 7-foot, ½ of which may be 4- and 5-foot).	3+	1+	[6] 25	(5)	1 ½ inches by 2 feet

Source: Wood handbook: Wood as an Engineering Material, USDA For. Serv., For. Prod. Lab. Agric. Handb. No. 72, rev. Aug. 1974.

[1] Inspection to be made on the poorer side of the piece, except in Selects.

[2] Firsts and Seconds are combined as 1 grade (FAS). The percentage of Firsts required in the combined grade varies from 20 to 40 percent, depending on the species.

[3] Same as Seconds with reverse side of board not below No. 1 Common or reverse side of cuttings sound.

[4] This grade also admits pieces that grade not below No. 2 Common on the good face and have the reverse face sound.

[5] Unlimited.

[6] The cuttings must be sound; clear face not required.

Figure 2. — Alder cutting grades[1]

Grade and lengths allowed (feet)	Widths allowed	Surface measure of pieces	Amount of each piece that must work into clear-face cuttings	Maximum cuttings allowed	Minimum size of cuttings required
	In.	*Sq. ft.*	*Percent*	*Number*	
Select and Better: 4+ (will admit 10 percent of 4 to 6 foot)	4+[2]	1+	83 1/3[3]	unlimited	4 inches by 3 feet, or 3 inches by 6 feet
No. 1 Shop: 4+ (will admit 10 percent of 4 to 6 foot)	4+[2]	1+	66 2/3[4]	do.	4 inches by 2 feet, or 3 inches by 3 feet
No. 2 Shop: 4+ (will admit 10 percent of 4 to 6 foot)	4+[2]	1+	50[4]	do.	3 inches by 2 feet
No. 3 Shop: 4+ (will admit 15 percent of 4 to 6 foot)	3	1+	33 1/3[5]	do.	do.

[1] Inspection to be made from the better side of the piece on rough or surfaced lumber, with pin knots considered to be no defect.
[2] Will admit 5% 3" wide.
[3] The reverse side of the cuttings must be sound or not below No. 1 Shop grade.
[4] The reverse side of the cuttings must be sound.
[5] The cuttings must be sound; clear face not required.

Differences in the Lumber Grade Structure of Alder and Competing Species

The principal types of lumber competing with red alder are from four east coast species, birch, yellow poplar, soft maple, and cherry, all of which are graded under the standard grades. The significant differences between the grade structures of Pacific coast red alder and these competing species lie in the following areas:

1. Dimension requirements of the Firsts and Seconds (FAS) standard grade vs. the Select and Better alder grade.

2. Determination of the grading face.

3. Limitation in the number of cuttings permitted to establish the required yield.

4. Dimensions of clear-face cuttings required in the Select and Better alder grade vs. the Selects and Firsts and Seconds (FAS) standard grades.

5. Alder is graded after kiln drying and surfacing.

EXPLANATIONS

Dimensional Requirements of the Firsts and Seconds (FAS) Standard Grade vs. the Select and Better Alder Grade

The Firsts and Seconds grade of the standard and hardwood rules has a minimum dimensional requirement of 6-inch width and 8-foot length. This is in contrast to the red alder Select and Better grade minimum dimensional requirement of 3-inch width and 4-foot length. Thus, for competing species, all pieces in a shipment of the grade of Firsts and Seconds must be at least of the minimum dimension; 6-inch width and 8-foot length. In contrast, a shipment of Select and Better grade alder could contain boards as small as 3-inch width by 4-feet long. In spite of these board dimension differences, however, the yield requirement for Select and Better alder and FAS are the same, i.e., 83-1/3 percent. Consequently, it should not be anticipated that, because of the smaller dimensions of Select and Better alder, any given volume would contain excessive volumes of short or narrow pieces.

Grading Procedure

It is the practice of the industry, when grading alder under the NHLA alder rules, to grade after kiln drying and surfacing both faces of alder lumber. The procedure allows for the removal of boards which should be downgraded due to defects incurred during drying and surfacing. This is a substantial advantage in contrast to other species which are graded in the rough green condition. Rough green grading cannot take degrade into account due to subsequent drying and surfacing operations.

Limitation in the Number of Cuttings Permitted to Establish the Required Yield

The number of cuttings permitted to obtain the required yield to establish the grade are limited in all competing species. In red alder the number of cuttings permitted to obtain the yield are unlimited. For example, in the standard grade of No. 1 Common, a piece containing 6 surface feet would be permitted two clear-face cuttings to obtain a yield of 66-2/3 percent, or one additional cutting if the total yield would be 75 percent or more. A maximum of three clear-face cuttings would be permitted to establish the grade of No. 1 Common. These cuttings must also meet the No. 1 Common minimum cutting size of 4 inches by 2 feet or 3 inches by 3 feet. In red alder No. 1 Shop grade, the number of cuttings to meet 66-2/3 percent yield are unlimited, providing they meet the minimum dimensional requirement of 4 inchs by 2 feet or 3 inches by 3 feet.

Dimensions of Clear-Face Cutting in Select and Better Red Alder and Selects and Firsts in the Standard Grades

Since red alder has a somewhat smaller lumber dimensional requirement, it is appropriate that the dimensions of the minimum size requirements for clear-face cuttings also be somewhat reduced. As shown in figure 3, the

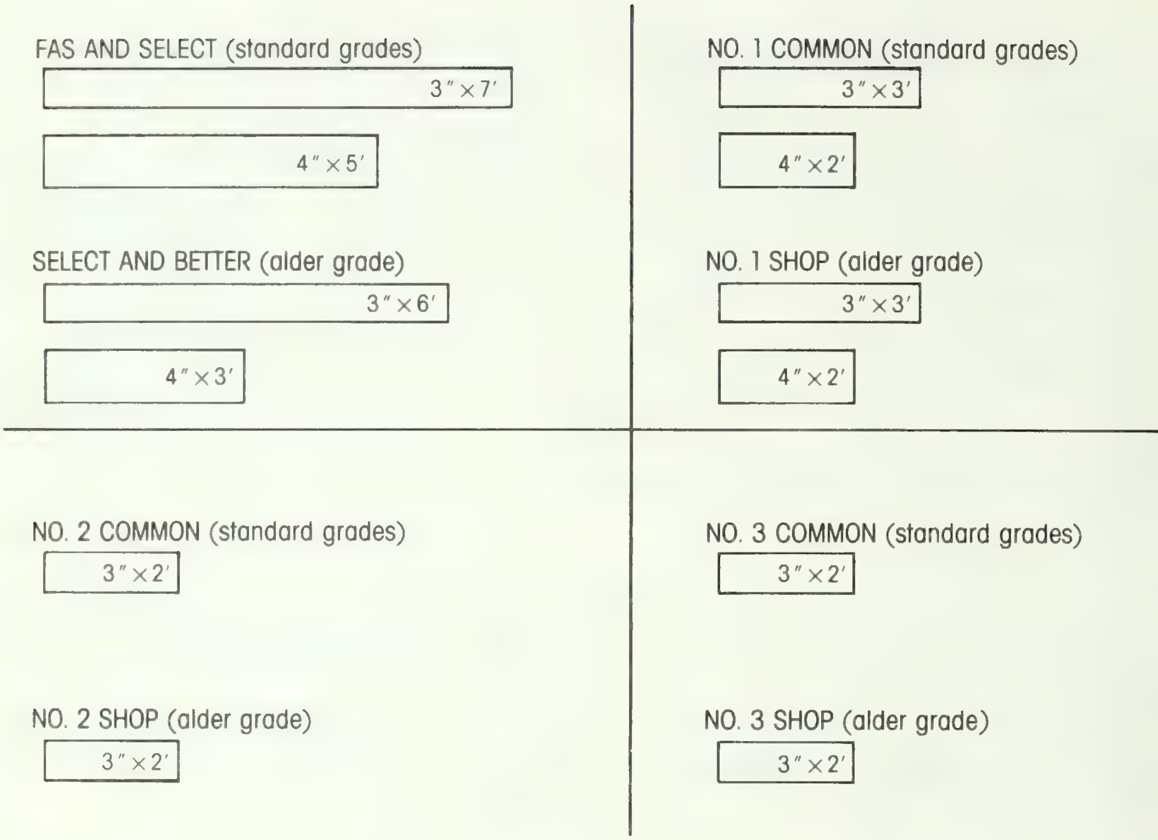


Figure 3.--Comparison of the minimum cutting size requirements of alder and standard hardwood lumber grades.

minimum clear-face cuttings for alder (which are 4 inches by 3 feet or 3 inches by 6 feet) are smaller than the cutting sizes required in the stan ard grades of Firsts and Seconds and Selects. Figure 3 also shows that there is no difference in the dimensional requirements of the cuttings in the standard Common grades and counterpart alder Shop grades.

Reference

(1) National Hardwood Lumber Association.
1978. Rules for the measurement and inspection of hardwood and cypress lumber. Chicago, Ill.

Appendix I

Introduction to the Fundamentals of Hardwood Inspection Procedures Relative to Grade Evaluation of Pacific Coast Red Alder

EFINITIONS

A cutting unit is a piece 1 inch by 1 foot.

A cutting is a portion of a board or plank obtained by crosscutting or ipping, or by both. In the Common grades, a cutting shall be flat enough o surface two sides to standard surfaced thickness after it has been reoved from the board.

A clear-face cutting is a cutting having one clear face (ordinary season hecks are admitted) and the reverse side sound as defined in sound cutting. he clear face of the cutting shall be on the poor side of the board except hen otherwise specified.

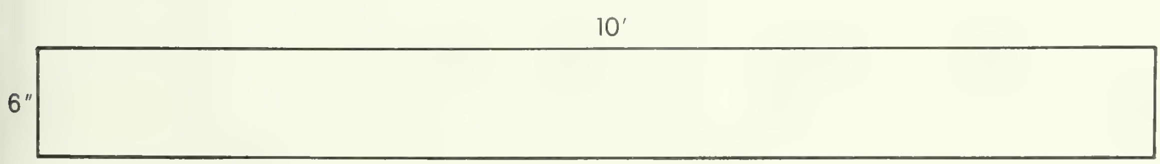
A sound cutting is a cutting free from rot, pith, shake, and wane. exture is not considered. It will admit sound knots, bird pecks, stain, treaks or their equivalent, season checks not materially impairing the trength of a cutting, and pin, shot, and spot worm holes. Other holes 1/4 nch or larger are admitted but shall be limited as follows: One 1/4 inch n average diameter in each cutting of less than 12 units; two 1/4 inch or ne 1/2 inch to each 12 units and on one side only of a cutting.

Wane indicates bark or lack of wood.

Pith is the small soft core occurring in the structural center of the og.

Stain in hardwoods is used to describe the initial evidences of decay.

CALCULATION OF NUMBER OF CUTTING UNITS, SURFACE MEASURE AND GRADE DETERMINATION OF A TYPICAL ALDER BOARD



1. To determine the number of cutting units, multiply width in inches by length in feet.

6 inches by 10 feet = 60 cutting units

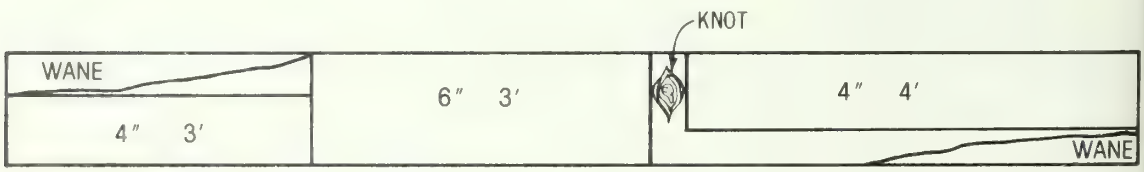
2. To find the surface measure, divide the number of cutting units by 12.

$$60/12 = 5 \text{ feet of surface measure}$$

3. The grade is determined by the percentage of clear tree cuttings from the better face of the piece by the cutting unit method. Applying the required yield percentages of the alder grades to the number of cutting units in this board results in the minimum yield of cutting units required by each grade for this board.

Alder grade	Grade yield requirement	x	Cutting units in board	=	Required cutting units by grade for board
Select & Better	10/12 or 83-1/3 percent		60		50
No. 1 Shop	8/12 or 66-2/3 percent		60		40
No. 2 Shop	6/12 or 50 percent		60		30
No. 3 Shop	4/12 or 33-1/3 percent		60		20

4. Now, suppose the above board had defects and cuttings as shown below.



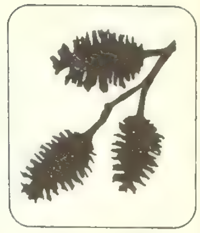
To determine the grade of the board, calculate the yield of the cuttings in cutting units and compare the total yield to the grade requirements determined in step 3. The cutting units in the three cuttings are

4 inches by 3 feet = 12 cutting units
6 inches by 3 feet = 18 cutting units
4 inches by 4 feet = 16 cutting units

These cuttings combine to yield 46 cutting units. This is insufficient to allow the board to make the Select and Better grade which requires at least 50 cutting units out of this board but the yield is sufficient to qualify the board in the No. 1 Shop grade.

On the basis of the sizes of the cuttings, the board would appear to qualify for the Select and Better grade. Figure 2 indicates that this grade requires cuttings to be at least 4" x 3' or 3" x 6'. The combined yield of these cuttings, however, is 46 cutting units which is less than the 50 cutting units determined to be the minimum required yield from this board, if it is to qualify as Select and Better. The board is therefore disqualified from Select and Better and is compared with the requirements of the next lower grade, No. 1 Shop. Since it meets the requirements of this grade, the board is graded No. 1 Shop.

STABILIZING COLOR AND DRYING RED ALDER



CHARLES J. KOZLIK
Forest Research Laboratory
School of Forestry
Oregon State University
Corvallis, Oregon

ABSTRACT

A honey-brown color is established without difficulty in drying freshly sawed red alder lumber, but a reddish-tan to reddish-brown color requires dry-bulb temperatures above 185°F at 92-percent relative humidity or higher. A white or ivory color is obtained by steaming freshly sawed or partially air-dried lumber at 212°F and 100-percent relative humidity. The white color may be retained with air drying, but a honey-brown to reddish-brown color requires kiln drying immediately after setting the color. Kiln-drying practices depend on kiln capacity, boiler capacity, availability of logs, log storage, and customer specifications. Initial dry-bulb temperatures range from 150° to 190°F, and drying times for 4/4 lumber vary from 4 to 6 days. Equalizing for uniformity of final moisture content and conditioning to remove drying stresses for remanufacturing are important steps in drying for both producer and customer.

Introduction

Red alder lumber must be kiln dried to satisfy customer demands for rade, moisture content, and color. Alder lumber 5/4 or thinner is one of ie easiest to dry in the United States; but thicker stock, such as 8/4 to 2/4, causes problems in kiln drying because of the time required--as much s 24 days. Moreover, the percent of degrade increases with thickness.

One difficulty is the setting of the uniform color, which is important o both producer and customer. Red alder varies in color from white to ellow to blood red immediately after the sawing of fresh logs. A study by archesy[1] reports that this staining phenomenon results from a novel iarylheptanoid xyloside, oregonin. Karchesy believes the chemical stain is aused by oxidation. The color of red alder lumber varies with site, time f sawing, log storage, and delay in kiln drying the lumber.

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[1]Karchesy, J. J. 1974. Polyphenols of red alder, chemistry of the staining ienomenon. Ph.D. thesis, School of Forestry, Oregon State Univ., Corvallis. 103 p.

Many sources suggest kiln schedules for alder lumber up to 2 inches. Schedules of time-temperature rather than moisture content-temperature are more convenient for the producer but do not guarantee the desired moisture content (MC) and range. Final average MC will vary with seasons of the year, time of log storage, and individual kilns. I cannot, therefore, present a kiln schedule that will fit everyone's needs but can only suggest methods to improve drying practices, reduce kiln time, and set uniform color in the lumber.

After a study in 1962 at the Forest Research Laboratory, we suggested drying at 200°F dry-bulb temperature, then considered the maximum temperature, with corresponding steep wet-bulb depression. We also showed that a more severe schedule would not increase degrade. Mills with modern kilns have increased drying temperature, and a few mills are beginning the drying cycle with temperatures of 180° to 190°F. An accelerated schedule will reduce drying times for 4/4 and 5/4 lumber by 30 percent without additional degrade and will produce uniform color. Boiler capacity restricts many mills to initial temperatures of 170°F or lower; however, the drying rate may be increased by increasing the wet-bulb depression.

Stabilizing Color

The initial setting of drying conditions in the kiln establishes color and uniformity. Anderson and Frashour (*1*) investigated conditions required to set light brown and found that color varied with time, dry-bulb temperature, and relative humidity. Industrial practice has shown that honey tan may be obtained by using dry-bulb temperatures from 140° to 150°F, with 5°F wet-bulb depression for at least 12 hours. Commercial kiln drying at 180° to 190°F with 10°F wet-bulb depression for 18 hours will also produce honey-tan.

In cooperation with Paul Barber Hardwoods Company, I determined the effect of kiln conditions on setting colors, preventing sticker stain and mottling, and removing stain from discolored lumber (*4*). We tested steaming at temperatures 183° to 205°F and relative humidities of 92 percent and higher for 6 to 15 hours. The results are shown in table 1. Charges 2D, 2E, and 2F, steamed at 190°F at 92- to 96-percent relative humidity and immediately kiln dried, were uniformly reddish tan after 7 hours of steaming, reddish brown after 12 hours of steaming, and dark reddish brown after 15 hours of steaming. The dry-bulb temperature was maintained at 190°F to complete drying.

Dry-bulb temperature was increased to 197° and 201°F and relative humidity to 100 percent for charges 2G and 2H, but the color did not vary except when the time was increased. Apparently, time has the greatest influence in setting color at dry-bulb temperatures of 190° to 205°F and corresponding relative humidities of 92 percent and higher.

We steamed matched charges 2DD, 2EE, 2FF, and 2HH at the same kiln conditions as those for charges 2D, 2E, 2F, and 2H. After air drying 3 to

veeks, the lumber was kiln dried to determine whether the color was sta-
lized. Twenty percent or more boards were mottled from honey tan to red-
sh tan. Results clearly showed that color is not retained if the lumber
steamed and then air dried in order to reduce demand on the dry kilns.
ost mills, including softwood mills, increase their kiln production with
celerated kiln schedules or partial air drying.)

Steaming of freshly sawed lumber at 212° to 214°F and 100-percent rel-
ive humidity from 2 to 6 hours produced lumber of white to ivory color.
ee table 1 for charges in series 1.) Tests showed that steaming at these
nditions for 4 to 6 hours produced the most uniform color.

Table 1--*Steaming conditions and color stabilization for random-width, 8 foot long, unseasoned, 4/4 red alder lumber*

	Steaming				Color stabilization			
						Final color		
ge[1/]	Dry-bulb temp	Relative humidity	Time	Kiln schedule[2/]	Mottled	Sapwood	Heartwood	Uniformity
	Deg F	Percent	Hours		Percent			
	212	100	2	L	0	White	Ivory	Excellent
	212	100	4	L	0	White	Ivory	Excellent
	212	100	4	L	8	White	Ivory	Excellent
	212	100	4	L	0	White	Ivory	Excellent
	212	100	6	L	7	Ivory	Ivory	Excellent
	212	100	6	L	0	Ivory	Ivory	Excellent
	212	100	4	L	0	White	Ivory	Excellent
	212	100	4	L	7	White	Ivory	Excellent
	183	96	6	L	31	Honey tan	Honey tan	Poor
	183	96	9	L	26	Honey brown	Honey brown	Poor
	183	96	12	L	45	Reddish tan	Reddish tan	Poor
	190	96	7	A	0	Reddish tan	Reddish tan	Excellent
	190	96	7	L	44	Reddish tan	Reddish tan	Poor
	190	92	12	A	0	Reddish brown	Reddish brown	Good
	190	92	12	A	20	Reddish tan	Reddish tan	Poor
	190	92	15	A	0	Dark red brown	Dark red brown	Good
	190	92	15	L	21	Reddish tan	Reddish tan	Poor
	197	99	12	L	13	Tan	Red tan	Good
	201	100	15	A	0	Dark red brown	Dark red brown	Good
	201	100	15	L	32	Reddish tan	Reddish tan	Poor
	205	100	6	L	36	Tan	Honey tan	Poor
	212	99	4	L	0	White	Ivory	Excellent
	212	100	8	L	14	White	Ivory	Good
	212	100	12	L	0	Ivory	Light tan	Excellent
	212	100	24	L	0	Ivory	Light tan	Excellent

[1/] Double letter suffix signifies charges that were steamed, air-dried for 4 to 6 weeks, and
-dried. Single letter suffix signifies charges that were kiln-dried immediately after
ming, except number three charges which were air-dried to 16- to 19-percent moisture
ent before steaming and kiln drying.

[2/] "L" signifies charges dried with initial dry-bulb temperature of 150°-155°F and finishing
80°F. "A" signifies a constant dry-bulb temperature of 190°-200°F.

Steaming air dried lumber at 212°F and 100-percent relative humidity for 4 to 24 hours (series 3, table 1) eliminated sticker stain and did not produce enough mottling to cause degrade. The moisture content of the air-dried lumber averaged from 16 to 19 percent before kiln drying. Steaming from 4 to 8 hours produced white in the sapwood and ivory in the heartwood steaming for 12 to 24 hours darkened the sapwood to ivory and the heartwoo to light tan. In all instances, the boards lacked luster. White can be established successfully by steaming freshly sawed or partially air-dried lumber up to 2 inches thick, but stain caused by an organism will not be minimized.

Color stabilization at high temperatures and relative humidities has several disadvantages. Drying temperatures near 190°F and 85-percent relative humidity cause excessive shrinkage. This effect was verified by Espenas (*2*), who studied the effect of kiln conditions on the shrinkage of red alder, Douglas-fir, and western hemlock. Red alder was most affected of the three species when dried at kiln conditions for 12-percent equilibr moisture content (EMC). Shrinkage at 215°F was more than double that of 90°F. Setting reddish tan or dark red brown in the lumber, therefore, cau a high percentage of thin boards or boards that had sticker markings after being surfaced from 4/4 to 15/16 inch. If boards were surfaced to 13/16 inch or less, color was uniform and sticker markings disappeared. Steamin at 212°F and 100-percent relative humidity for a white color did not cause excessive shrinkage when all charges were dried at initial 150°-155°F dry-bulb temperatures.

Another disadvantage of high-temperature steaming is that only a mode kiln can attain the temperatures and relative humidities required and, ove a period of 2 years, will require more maintenance than kilns drying red alder lumber at usual temperatures.

Kiln Drying

Setting a honey-brown color in the lumber is the first step in the drying schedule. Initial dry-bulb temperatures of 150° or 180°F with corresponding wet-bulb depression of 5° or 10°F is sufficient to induce drying. I have determined no difference in degrade or loss of clear cutti units in drying at 150°, 180°, and 200°F (*3*).

After the color is set in 12 to 18 hours, the second drying cycle may be quite severe for 4/4 lumber. An EMC condition of 6 percent, compared t 9 or 12 percent, did not cause additional degrade or loss of clear cutting units. The amount of small end checks, the amount of checking in knot areas, and the general appearance of lumber dried at 200°F and 6-percent EMC were not favorable, however, when compared to results of a commercial schedule with an initial dry-bulb temperature of 150°F that ended in 5 day at 180°F. The change from conditions for high EMC in presteaming to conditions for 6-percent EMC (at 200°F) made kiln control difficult. When this sudden change was made, the heating system was on full demand, the vents remained wide open from 1 to 2 hours, and considerable heat was wasted.

mall end checks and checking in the knot areas were eliminated when condi-
ions for 10- or 11-percent EMC were held for at least 12 hours before set-
ing for 6-percent EMC. This reduced the amount of initial venting and
aved heat.

The conventional dry kiln has ample air velocity to maintain an adequate rying rate. Kilns constructed 20 years ago have air velocities ranging rom 400 to 450 feet per minute with proper baffling and loading. Perhaps he chief fault in drying is improper baffling or no baffling at all. Drying time is reduced about 30 percent if air velocity is increased from 150 o 600 feet per minute; the higher air flow generally assures more uniform rying throughout the charge. Frequency of fan reversal is dependent upon any variables, such as width of load, desired rate of moisture removal, and iln construction; but uniformity of final MC is tied to the capability of ir circulating in the kiln to remove moisture from wood surface regardless f its location. A low temperature schedule designed to dry 4/4 lumber in or 7 days requires fan reversal about every 12 hours. An accelerated chedule lasting 4 days requires fan reversal every 6 hours.

When 4/4 lumber is kiln dried, the wet-bulb depression usually is in-reased 10°F every 24 hours with an accelerated schedule (190°F), and 5°F ith a low temperature schedule (150°F). Drying times are approximately 4 ays for an accelerated schedule and 5-1/2 days for a low-temperature chedule.

To present an optimum schedule for everyone's requirements is not ossible. End or surface checking will occur in the first 24 to 48 hours or 4/4, 5/4, and 6/4 lumber on a low temperature schedule (150°F). For hicker stock, such as 10/4 or 12/4, the first 5 or 6 days are critical. fter the initial period, the checks tend to close; but at fiber-saturation oint, or about 28-percent MC, shrinkage becomes noticeable as warp. Cup nd twist cause the largest loss of grade because of roller split during achining. When these occur, the schedule should be adjusted. Checking is aused by severe drying conditions or too rapid drying. Dry-bulb tempera-ure need not be reduced, but the EMC conditions should be raised or the spread between wet- and dry-bulb temperatures decreased.

Procedures to reduce warp in lumber start in the sawmill with close olerances for sawing, especially for thickness. Stickering and piling ractices also will influence the amount of warp. Stickers should be placed every 2 feet and aligned well within the package and with stickers in pack-ages above and below. Tiers of stickers should be supported by the bunks on he kiln trucks. The top three to five courses will have more warp than the thers because no restraint is provided.

Most hardwood mills dry 4/4 to 6/4 lumber to an average MC of 6 to 8 ercent. When the lumber is nearly dry, conditions for equalization are set o reduce final MC to the desired average within a predetermined range. Equalization is dependent on time, EMC conditions, MC before equalizing, and desired uniformity of final MC. Table 2 shows the effect of these variables on 4/4 lumber when equalized to a 7-percent average MC± 2 percent. Condi-

Table 2--*Results of various kiln conditions in equalizing and conditioning for 4/4 red alder lumber*

		Equalizing					Conditioning			
			Kiln final moisture content							
Charge	Initial moisture content[1]	EMC	Time	High	Low	Avg.	Time	Dry bulb temp.	EMC	Stress relief
	- -Percent- -		Hr	- - -Percent- - -			Hr	°F	Percent	
6A	14.6	4	9	12.0	8.5	9.8	10	204	12	Good
6B	8.4	5	15	8.0	7.0	7.2	12	165	11	Excellen
6C	15.2	3	17	9.5	<6.0	7.1	7	200	10	Good
6D	8.0	4	9	9.0	7.0	7.6	11	190	11	Excellen
6E	10.0	4	19	9.0	7.0	7.3	11	190	11	Excellen
6F	<12.0	5	7	10.5	7.0	8.5	7	200	16	Excellen
6G	11.9	5	14	8.5	7.0	7.5	5	200	13	Good
6H	16.2	5	14	12.0	7.5	8.3	5	200	14	Fair
6I	>11.0	5	5	11.0	7.0	8.2	6	200	16	Good
6J	13.4	4	4	12.0	9.0	10.2	7	190	18	Excellen

[1] Average before equalization.

tions for EMC of 3, 4, or 5 percent were tested to bring final moisture content down to a narrow range in a short time. For charge 6C, condition for 3-percent EMC were effective in lowering boards with high MC to 9.5 percent. Some boards had less than 6-percent MC, which is probably undesirable for remanufacturing. Best results were obtained with conditions for 4- or 5-percent EMC.

Moisture content at the start of equalization influenced the range c final MC. For example, charges 6A and 6D were held at 4-percent EMC for hours. Charge 6A ended with a range of final MC of 3.5 percentage points and 6D, which began equalization with 8.0-percent MC, ended with a range 2.0 percentage points (table 2).

Length of the equalization period also affected the range of final MC In charges 6G and 6I, which had nearly the same initial MC, 14 hours of equalization reduced the range of final MC to 1.5 percentage points and 5 hours to 4.0 percentage points (table 2).

Study of results in table 2 shows that holding conditions for 4- or 5-percent EMC for 7 hours, with an additional hour for each percentage point of MC desired, will bring the range of final MC down to about 2 percentage points. When the wettest kiln sample registers 14 percent or mor however, this rule of thumb is doubtful. Also, equalizing 5/4 or 6/4 lum will require additional time.

Another rule of thumb is to set conditions for EMC 3 percent less than desired average MC when the wettest sample has 2 percent more than the ired average MC. Equalize until the wettest sample has less than 1 per-t over the desired average MC. No two charges will dry the same, so n samples or hot moisture-meter readings taken in the kiln are needed to ermine the MC before equalizing. One hot meter reading per 1,000 fbm uld be taken until you are confident of the figures, then the sample size be reduced.

The producer and customer usually agree on the final MC of the lumber usually do not discuss removal of drying stresses or relief of case-dening in remanufacturing stock until the customer complains of distor-n of his cut stock. Casehardening can be relieved only by conditioning the kiln and is accomplished best with the highest dry-bulb temperature EMC conditions that are controllable.

We held conditioning at dry-bulb temperatures between 190° and 200°F, ept for charge 6B, which was held at 165°F in a commercial schedule ble 2). We rated relief of stresses with cut-prong samples similar to se shown in figure 1. The prong samples were rated visually as excell-(no casehardening present), good (slight casehardening), or fair (slight severe casehardening).

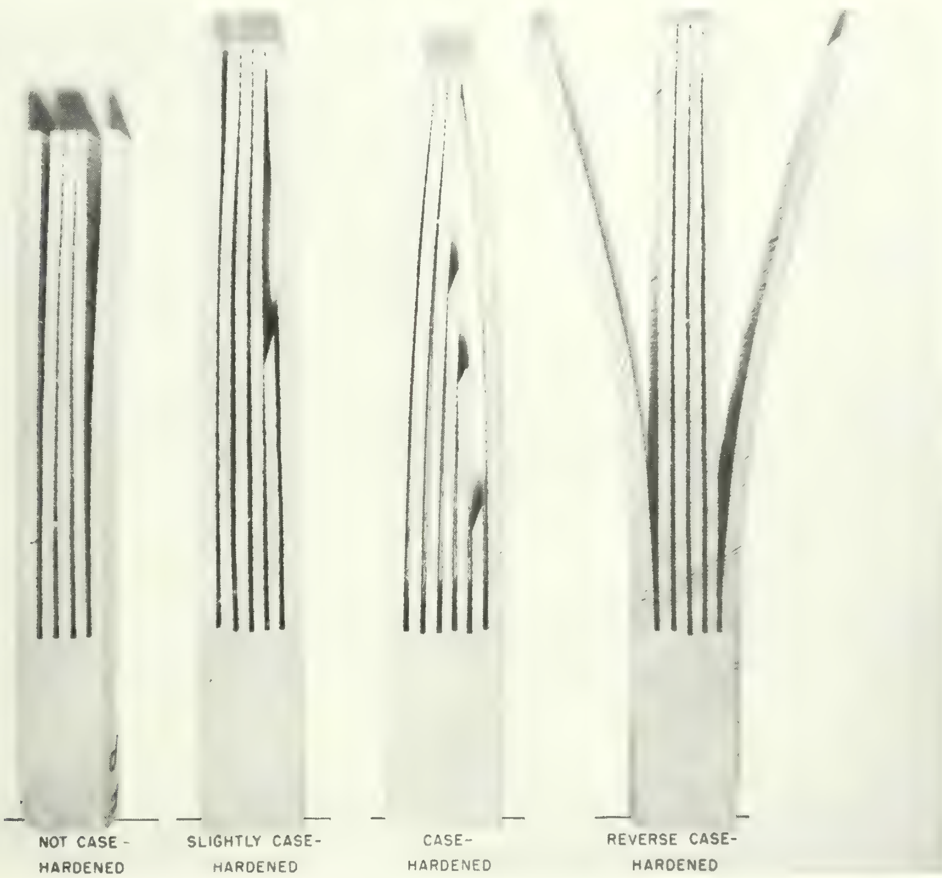

Figure 1.--Comparison of drying stress after conditioning.

Relief of casehardening stresses under conditions common to commercia practice required 11 hours at settings for 11-percent EMC, as in charges 6B, 6D, and 6E. If a commercial kiln could maintain conditions for 16- to 18-percent EMC, as in charges 6F and 6J, the time required for relieving stresses could be shortened to 7 hours. Time cannot be reduced much more, as shown by charges 6H and 6I, which did not demonstrate adequate stress relief.

The range of MC before conditioning is of major importance. Charges having a wide range in MC, such as 6H and 6I, required prolonged condition ing at high EMC conditions with only fair to good relief of casehardening. Therefore, range of MC before conditioning, time of conditioning, and EMC conditions are closely related. The thicker the lumber, the longer the conditioning period required. If you now require 12 hours to condition 4/4 lumber, 5/4 lumber will require about 16 hours, 6/4 lumber about 20 hours, and 8/4 lumber as much as 30 hours.

I have been deliberately evasive about wet- and dry-bulb settings and times for drying, equalizing, and conditioning. Each charge of lumber is different, as are kilns, operators, and customers' specifications. For problems with a new drying installation or with your present system, sever State and Federal agencies offer assistance:

Charles J. Kozlik
School of Forestry
Oregon State University
Corvallis, OR 97331

Donald G. Arganbright
California Forest Products Laboratory
1301 South 46th Street
Richmond, CA 94804

David P. Thomas
College of Forest Resources
University of Washington
Seattle, WA 98105

George Bramhall and J. F. G. MacKay
Western Forest Products Laboratory
6620 NW. Marine Drive
Vancouver, BC, Canada V6T 1X2

The drying process or any process in the mill will be as good as the quality-control program you have implemented. Think of quality-control no as a group of figures requiring statistical analysis but rather as a means of collecting information for improving your product.

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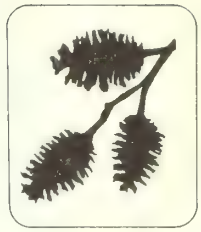
ALDER–SHOULD WE CHIP IT OR SAW IT?



ROD L. REMINGTON, Production Manager
Centralia Division
Northwest Hardwoods, Inc.
Centralia, Washington

ABSTRACT

It has been stated that the manufacture of red alder lumber is a small mill product; however, Northwest Hardwoods, Inc. has taken giant strides toward changing that image. Quality control and lumber sense are the key words that describe our operations goals. From expanded log consumption, constant machinery and process updating, to satisfied customers Northwest Hardwoods, Inc. has taken the Mom & Pop approach out of manufacturing alder.

Introduction

In years past, alder was a weed to be cleared from the land so that some form of softwood could be encouraged to develop. The potential for harvesting alder was not even considered. We have poisoned and spent thousands of dollars to remove this species from our land, and yet it continues to grow and flourish. As small sawmills began to spring up, many with only four or five employees including the working owner, some of the better sawlogs were brought in out of the woods. These mills were small and struggling to keep costs down, and there were many restrictions placed on the incoming log. The diameter needed to be of good sawlog size; and in many cases, the length had to be held short as unloading was often performed by the mill's only forklift. Chips weren't even thought of. It was all the mills could do to process enough logs to keep in business. All trim and edgings went into the fuel wood market - bark and all.

As in many instances, the hardwood chip was discovered by most sawmills through necessity. As the sawmills grew in lumber output, the firewood market stayed relatively constant and, in some areas, dwindled in favor of less troublesome fossil fuels. This left the mills with the alternative of finding new markets for residuals or closing down.

Debarking

In 1959, the first alder hardwood residual chipper went into operation at Centralia Hardwoods, and with it a Nicholson "coon hound" Rosser Head Debarker to remove the bark and provide a clean residual chip. The chips were mixed with sawdust and sold to a firm that was producing a corrugation medium.

The Rosser Head produced a block that was totally bark free but, in th process, removed vast amounts of wood and slivers. To improve the quality of debarking, a "32" Nicholson Ring Debarker® was installed in 1965. With the new debarker came the opportunity to consider more chipping as the new debarker's speed provided enough logs to keep the mill operating with time left over.

At this point, the decision was made to install a whole block chipper in the mill to upgrade the mill's saw block. This new chipper allowed us experiment with the log mix coming into the mill. It was slow in todays standards, but at that time it placed us in the business of selling an increasing volume of clean whole log chips.

Today, with the availability of higher speed debarkers and increased interest in alder chips, we have elected to develop a modified merchandisi line capable of handling a larger volume of woods run resources.

Today, we handle whole loads of logs with the use of heavy equipment allowing a quicker turn around for the trucks.

We deck each log with hydraulic loaders to facilitate more storage an insure a year-round operation. We have expanded our maximum inventory to the point that we are capable of storing 300 percent of what we stored 8 years ago and are using only 15 percent more land. This insures our sustained operation and allows those hauling to us the security of knowing we will be receiving logs year-round.

Merchandiser

In merchandising, there are two basic theories of operation: (1) Debarking the long log and bucking after debarking. It is felt that the quality of the log can better be evaluated with this method. (2) Our mill prefer bucking prior to debarking. We feel bucking ahead of the debarker allows us some advantages in removing the bark from the more crooked logs. Through our design, we are able to debark long straight chip logs without bucking or recover only a single saw block from an otherwise chip log.

As the log enters the merchandising line, we are faced with the first and most important decision: "Should we saw it or chip it?" To answer th question, each mill operator has to establish his own guidelines. He must recall all of his knowledge about his individual lumber market restraints, chip recovery values, and most important, his current resource, both volum available and cost. With this input, a graph can be developed so that the individual mill operator can evaluate his options. In graphing the option we find the merchandiser operators can be given general instructions for t logs having diameters between 8 and 10 inches.

Probably the single most troublesome feature in any operation, softwo or hardwood, is the attitude and discipline that occurs in the woods.

In designing any merchandising line, there are a number of considerations--those that are of paramount importance concern the volumes of byproducts that must be hauled away.

There are some weight considerations when dealing with alder. If you are going to saw all your logs, you would have to handle only 20-25 percent of the weight in the form of chips; if you were going to chip all logs, you would have to allow for 85-88 percent of the weight to be in the form of chips.

Once we have made the decision to saw rather than chip, we must again concern ourselves with alternatives based around the resource and the mill's marketing plan.

The Sawmill and Lumber Sense

At the headrig, we are presented with a block from the merchandiser that is free of bark and ready to be processed into alder lumber. The headrig area is slightly different in each mill. Some use the circle saw headrig, some the single-cut band mill, and in our case, the double-cut bandmill. Our goals are the same: to maximize flat grain lumber and orient the block to minimize undesirable defect structures such as spike knots. The output from our band mill has increased 20 percent during the past 2 years; however, our sawing time per saw line has not significantly changed. Our principle mechanical improvements have occurred in the carriage loading and block turning times. Aside from mechanical changes, we have spent a great deal of time and effort training our sawers to operate with "lumber sense"--the keys being quality and product control.

Every saw and saw system has its limits of performance. Each management team must determine where the trade off between recovery and output lies for their operation. Each philosophy has its merits and, for their operation, meets their marketing needs. The ultimate method of sawing for grade recovery would be total breakdown on the headrig - constantly turning the log and evaluating each board on its merits. The opposite extreme would occur if maximum volume was obtained by sending a whole log through a sash gang or possibly a quad band. We prefer to break down the block on two sides with the grade of the opening face as the control factor for the sawyers' decision. Once all the obvious #1 Shop and Better has been removed from the two opposite faces of the block, the resulting cant is sent to the circle gang where it is positioned to be fed through the saws, contingent on our historical recovery data, the market, and the judgment of the operator. This method does not maximize the grade recovery out of every block; however, we have developed our lumber markets contingent on our historical grade and volume recovery with this method. Throughout the operation, the key is on "lumber sense" and quality. Once missawn, a 4/4 board cannot be recovered and is lost forever. Our green lumber standards call for a maximum variation of 1/16 inch. We have fulltime quality control personnel along with our filers constantly monitoring the lumber for both thickness control and general product attitude. Should a deficiency be detected in our production,

we shut down or isolate the contributing unit until it can be repaired. In a production situation, it is difficult to establish an attitude of quality; but once established, it becomes as much a goal as production.

We have experimented with a variety of saw thicknesses, numbers of teeth, types of guides, methods of cooling, and saw change periods over the past years and, based on our green lumber quality standards, have elected to use thin plate carbide saws with air-water cooling.

Hardwood Softwood Yield

Compared to the softwood 1-inch board which, when dry and finished, sells at a net thickness of 3/4 inch, our alder 4/4 must dress out to a net thickness of 15/16 inch or 25 percent more wood. In comparing with a 2-inch softwood product which nets out at 1-1/2 inches, we must provide an additional 29 percent to net out at 1-15/16 inches.

Selling lumber random width as we do in the hardwood industry allows us to make the most pronounced recovery improvements anywhere in our mill at the board edger. When comparing the softwood products to the hardwood products, one finds that a board foot of softwood doesn't equal a board foot of hardwood. Let's look at an example: A softwood mill selling eight pieces of 2x6x10 will sell this lumber as 80 board feet; but when we check what the customer receives, we find that he received eight pieces 1-1/2" x 5-1/2" x 10', or a total of 55.04 board feet of actual wood. Our hardwood customer who settles for random width would, in this case, require us to provide a total of 44 inches width by 10 feet x 1-15/16 inches thick. We do not get any value from the shrinkage that occurred in the kilns, so the customer pays for 71 board feet and receives 71 board feet of actual wood. In summary, this says that we must, in order to meet the requirement of our customers, supply them with 32 percent more actual wood in order to develop the same volume sales as the softwood industry.

Board Edging

Bearing in mind that our recovery is contingent on the amount of actual wood we deliver to the customer, let's look at the board edger. Our board edgerman reviews and rips 40-43 percent of our total piece count coming out of the mill so, needless to say, we have spent many hours evaluating and training our edgerman. We have given him expensive laser lights to set his saws and require him to inspect and make necessary adjustments every 4 hour to insure his sawing is accurate and precise. Let's examine what could happen if the edgerman's saw on one side was sawing into the sound wood instead of coming out of the wane for a single shift. The average edger saw cuts a 1/4-inch kerf so we are only talking about 1/4 inch on one edge of 43 percent of all boards for one shift. For example:

.250" x 9.1' long = .1986 board feet
.1895 board feet x an average #2 shop price of $160/MBF = 3¢

ow you are saying that 3¢ isn't much but remember that this edger is reviewing 40-43 percent of your product so 3¢ by 4,730 pieces per shift equals 141.90 per shift. Extended on the basis of one shift for 12 months, all /4 thickness, shows a loss of $37,000. That's a little more significant! hat has happened to that 1/4 inch? If you are lucky, it would make chips nd yield an annual amount of about $7,000, but more likely it went into awdust and you received at best $1,500-$2,000. With the difference, you ould have placed a very expensive man on your payroll.

There is another aspect that makes the board edger in a hardwood mill ore complex. Within the grading rules there are wane allowances. In some ases, an extra 1/2 inch of wane left on a certain portion of the board will ower it to the next grade and, from a dollar standpoint, the best of our ecovery attempts is negated. Because of the complexity of the operator's ob, especially within the wane allowances, he often over-edges the board to e safe. Each mill has to place the level of importance of the board edger ob where they feel it best meets their needs.

Upon leaving the board edger, each board is reviewed once again by two en who can direct the board back to the edger if they feel additional edging is required.

Trimmer

Within our operation, the trimmer is used to equalize and end trim lumber prior to entering a mechanical sorting system.

The board passes through the trim saws and trips a length sensing limit switch then goes under a floating wheel and is sensed for thickness. These two sensings are sent through an electronic storage unit which times the boards and deposits them in the appropriate tray. On each tray there is enough accumulated lumber of the same thickness and length to make one package of green lumber. When the tray is full, it can be emptied individually, run across an automatic stacker, stickered, and collected into a bundle ready for the dry kilns. We selected this tray sorter and mechanical stacking system about 3-1/2 years ago in an attempt to reduce our mounting labor costs and improve the quality of stickering. To date, I am happy to say it has operated with a minimum of problems and we are handling 20 percent more lumber than when we had our green chain. In addition, this operation takes only three men in place of five to six men on the green chain.

An an added advantage, our Arlington Mill is using Simpson EKS stickers with excellent success.

Kiln Drying

In years past, we felt we had to air dry our lumber to reduce our drying costs and to improve our drying quality. Today, we feel more comfortable in getting the fresh lumber into the kilns and under a controlled

climate. All lumber is kiln dried prior to sale with the 4/4 dried to a moisture content of 6-8 percent and all other heavier thickness' dried to a 6-9 percent moisture content. Once we feel the lumber has had adequate residency, we open the kiln and check the lumber with a prong meter. If the meter indicates we are close, we cut ovendry samples from random areas within the kiln load and run them through a microwave oven to guarantee the kiln is at the correct moisture content. When drying material over 4/4 in thickness additional prong tests will be cut to determine if the lumber is properly conditioned and ready for the customer. Only at this time will we empty the kiln into the storage ahead of the planer.

Abrasive Planned

In 1972, Northwest Hardwoods installed an abrasive planer at our Arlington plant and explored its potentials for our customers. The planer was a Kimwood batch feed, four-head 36-inch abrasive planer powered with a direct coupled 100 hp motor on each head. We operated the machine for 2 years modifying the dust handling system to provide fuel for our boiler and working with the abrasive belt manufacturers to improve the life of the belts. Upon evaluating our customers reaction to the abrasive planer, we found even better response than we had originally expected. In 1974, we installed another abrasive planer at Centralia. This was also a Kimwood, batch feed, four-head machine, but this time we installed a 50-inch machine with a 200-hp motors on the primary heads and 150-hp motors on the finish heads. Sound absorbing material was attached to the Centralia machine to lower the noise level to an acceptable limit.

More details on the qualities of abrasive planing could be mentioned, such as the fact that our finish is the same from the beginning of the run to the end of the day. If the finish is not satisfactory, or we want a smoother finish, we change the belts, an operation which takes about 1 to 3 minutes. There are no roller splits, knicks, snipped ends, or grain tear out around the knots or any other planing defects associated with many knife planers. If we get an equivalent to a knick in a knife planer, we get a blown belt, which, when changed in 1 to 3 minutes, eliminates the surface imperfection. The abrasive planer is so accurate that our quality control standards call for shut down of the machine if the thickness tolerance varies more than .005 inch. The inspectors, machine operators, and our quality control staff constantly check the thickness tolerance with dial calipers and insure that surface appearance is within standards.

Northwest Hardwoods is not prepared to disucss the costs involved; however, we can assure you that our per unit costs are consistent with the quality of our product, and we feel sure our product is second to none. Any high speed, highly accurate machine requires more than normal maintenance.

Inspection

Our inspectors are highly trained employees who have been with the ompany for years and have proven their ability to maintain a consistency of rading accuracy above 95 percent, which I feel very confident is more than omparable with the industry averages.

As mentioned previously, we have placed special emphasis on quality ontrol and the "lumber sense" approach throughout our manufacturing facility.

Once packaged, all bundles take on similar appearance, irregardless of oard thickness. The bundles are prepared in the same physical size units nd tallied. Special emphasis is placed on tally because many units will anifest occasional short pieces, and we are very careful to deduct for the hort pieces so that the customer receives 1 board foot for each board foot e purchases. We welcome and encourage all of our customers to secure one f our tally computer cards and check our tally accuracy.

As one of the final quality control functions, random packages are elected from inventory, broken down, and a complete grade check and stick ally is performed. This is done to at least two bundles per day.

As proud as we are of our product, we never allow any lumber to leave ur mills without being totally protected from moisture and dust by insuring ll truckoads are fully tarped and all carloads are in sound cars.

Through all phases of our operation, we have placed special emphasis on uality and "lumber sense"--in merchandising the log, sawing the lumber, dging, handling the green lumber, drying to specific moisture contents, brasive surfacing and the final step of dust and moisture protection while n transit.

I would like to leave you with the thought that alder, like all of ature's creations, lends beauty to the Northwest and brings peace of mind o many of us.

TRENDS AND TECHNOLOGIES IN SOUTHERN HARDWOOD SAWMILLS

FRED J. HILL
Hardwood Lumber Project Manager
Union Camp Corporation
Franklin, Virginia

ABSTRACT

This paper examines several hardwood sawmills ranging in capacity from 5 MM bd. ft. to 40 MM bd. ft. annually, and discusses the relative capital costs, operating costs, and characteristics of each facility. The paper further relates hardwood sawmill design to the characteristics of the hardwood sawtimber resource in the Eastern United States and explores the major industry concerns of (1) lack of growth in hardwood lumber production, (2) reduction in log size and quality, and (3) shifts in end-use markets. The uncertain supply of hardwood logs from small private ownership, the lack of market growth, and the variable earnings history of hardwood operations have discouraged most large corporate investment to date.

Introduction

Thank you for inviting me here today. I am delighted to have the opportunity to participate in your program. It's my first meeting with many of you, and I look forward to continuing these acquaintances in the future.

A little background might be in order for those of you unfamiliar with Union Camp. Our historic business, and still the core of the company, is the manufacture of bleached and unbleached grades of paper and paperboard. These are produced in four mills. About half of the mills' output is converted into bags, boxes, printing papers, and business papers in our own network of converting plants. The remainder is sold to other converters or merchants.

The 1.7 million acres of woodlands, which we own in six southeastern States, provide the raw materials for our mills. To maximize the return on our woodland assets, we have also entered other fields. The company is one of the largest pine lumber producers east of the Mississippi. Union Camp is also the largest manufacturer of wood-based chemicals in the forest products industry. Other activities related to our landholdings include commercial and residential land development, mining, and finally, we operate a chain of 48 building material and home improvement centers in the southeast.

Compatible with our need for raw material for bleached paper productio and the desire to maximize returns on our woodland assets, Union Camp entered the hardwood lumber business last year. We now produce in excess of 24 MM bd. ft. It is my responsibility to evaluate and implement a major expansion of our hardwood lumber activities. It is my assignment today to share my knowledge of hardwood lumber manufacturing in the East. My commen will concentrate on five hardwood sawmill layouts ranging in single shift capacity from 5 to 40 MM bd. ft. annually. I will discuss the relative capital costs, operating costs, and general characteristics of each.

My basic objective is to stress the relationship between the characteristics of the hardwood sawtimber resource in the East and sawmill design. There are precious few innovations in hardwood manufacturing, but there are many changes in the resource acceptable for hardwood lumber. This Conferen typifies the trend toward new species, smaller logs, lower grades, and shorter lumber.

Eastern Hardwood Resource

The sawtimber resource in the Eastern United States is comprised of about 12 species with oak predominating (table 1). In many areas of the South, oak, sweet gum, and yellow poplar account for about 75 percent of th sawtimber resource; but the many "miscellaneous" species and our lack of ability to control log flow by species present problems.

Table 1--*Volume of eastern hardwoods*

Species	Volume	Proportion
	Million cu. ft.	Percent
Select white and red oaks	32,613	16.5
Other oaks	38,796	19.6
Hickory	12,582	6.4
Hard maple	11,732	5.9
Ash, walnut, and black cherry	12,185	6.2
Sweetgum	10,527	5.3
Yellow-poplar	8,566	4.3
Yellow birch	3,249	1.6
Other	67,426	34.2
Total	197,676	100.0

This multitude of species creates problems in cruising and buying timber, scaling logs, log yard storage, and inventory management by species. We operate our pine mills with only a 2-day inventory but our hardwood mill require a 15-day supply for efficient operation.

U.S. Forest Service Forest Survey data indicates that hardwood growth exceeds removals by almost 2 to 1, but our sawtimber resource is getting smaller. Reduced log size results in a decrease in hardwood lumber grade yield. On our timberlands, one-third of the hardwood sawlog resource consists of logs below 12-inch d.i.b. Many hardwood sawmills in the South are for sale today because they cannot efficiently convert these smaller, lower quality logs.

Changes are occurring in the end uses of hardwood lumber (table 2). The furniture industry has traditionally been the major consumer of hardwood lumber. The pallet, container, and box market continues to increase, however, and is now our major consumer. Whether this has stimulated low grade lumber production or resulted from it, I cannot answer.

Table 2--*Sawn hardwoods--estimate of major end uses*

Item	Years		
	1971	1972	1973
	- - - - -Percent- - - - -		
Furniture	34	33	29
Pallets	28	22	34
Containers and boxes	11	14	*
Crossties	11	14	13
Flooring	8	9	9
Laminated decking	3	4	8
Others	5	5	7
Total	100	100	100

*Included in pallets.

While consumption patterns are changing, total hardwood lumber production has not changed in 9 years. There is little reason to expect large production increases in the future in my opinion.

Estimated hardwood lumber production

Year	Million bd. ft.
1967	7,430
1968	7,188
1969	7,482
1970	7,138
1971	6,949
1972	6,770
1973*	7,008
1974*	6,904
1975*	5,506

*Subject to revision.

Source: Fingertip Facts and Figures, Natl. For. Prod. Assoc., Washington, D.C.

RESOURCE CONCLUSIONS

The changes in the acceptable hardwood sawtimber resource are setting the trends in sawmilling. The volume of hardwood timber is adequate, but diameter and quality are decreasing. Consumers are adapting to the changes in hardwood lumber size and quality but total consumption remains constant. The hardwood sawmill industry must adapt to these trends more rapidly in th 1980's than it has in the 1970's.

Production Alternatives

Let's turn our attention now to several hardwood lumber production alternatives. Presented in the next few pages are five sawmill layouts with varying debarking and breakdown equipment. If your background is in softwood lumber manufacturing, these mills will appear unsophisticated; but the eastern hardwood industry is less sophisticated than the pine industry.

MILL LAYOUT #1

The simplest sawmill considered has a capacity of 5-7 MM bd. ft. annually (fig. 1). It consists of a rosser head debarker, circle headrig, combination gang and board edger, and a two-saw trimmer. This mill can be constructed for about $800,000 excluding land costs, would develop sales of about $1.1 million and would have operating costs in excess of $700,000 annually. This mill does not have facilities for stacking, drying, or surfacing lumber. Ties, timbers, and pallet lumber would be the major products. The mill, representing the "modular mill" concept, is of the type Union Camp would use on 12-20-in hardwood logs of woodsrun quality.

MILL LAYOUT #2

The second layout represents a circle mill with an 8-in single-arbor gang edger, plus a board edger. The mill still utilizes a rosser head debarker, and a two-saw trimmer (fig. 2). This mill can be constructed for about $1.8 million, has an estimated production capacity of 10 MM feet per year. Operating costs would exceed $1.3 million on annual sales of $1.7 million. While the return-on-investment is lower for this larger facility, this mill design is more flexible than the previous mill. Separating the board and gang edger slightly increases capacity, reduces total mill downtime, but requires an additional employee. The increased flexibility to adjust product mix to market changes may offset a slight reduction in ROI. This design probably represents the most common hardwood sawmill in the South today.

MILL LAYOUT #3

This third layout represents a sawmill offered to us for acquisition. The mill is basically the same as Mill 2 with a gang edger. Mill 3, however has two rosser head debarkers, a drop saw trimmer and a production capacity of 12 million board feet annually (fig. 3). The construction cost for this

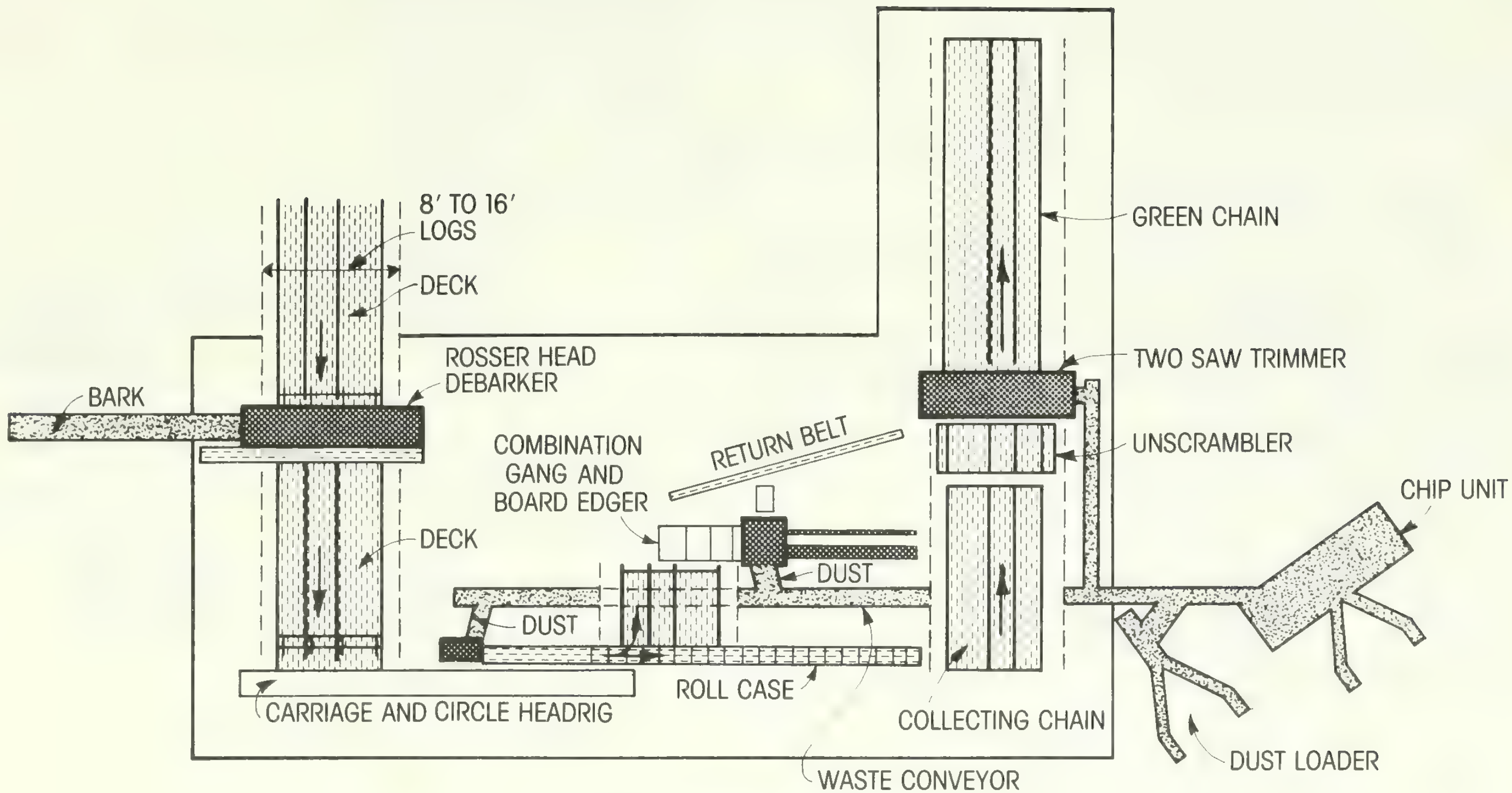


Figure 1.--Sawmill layout 1.

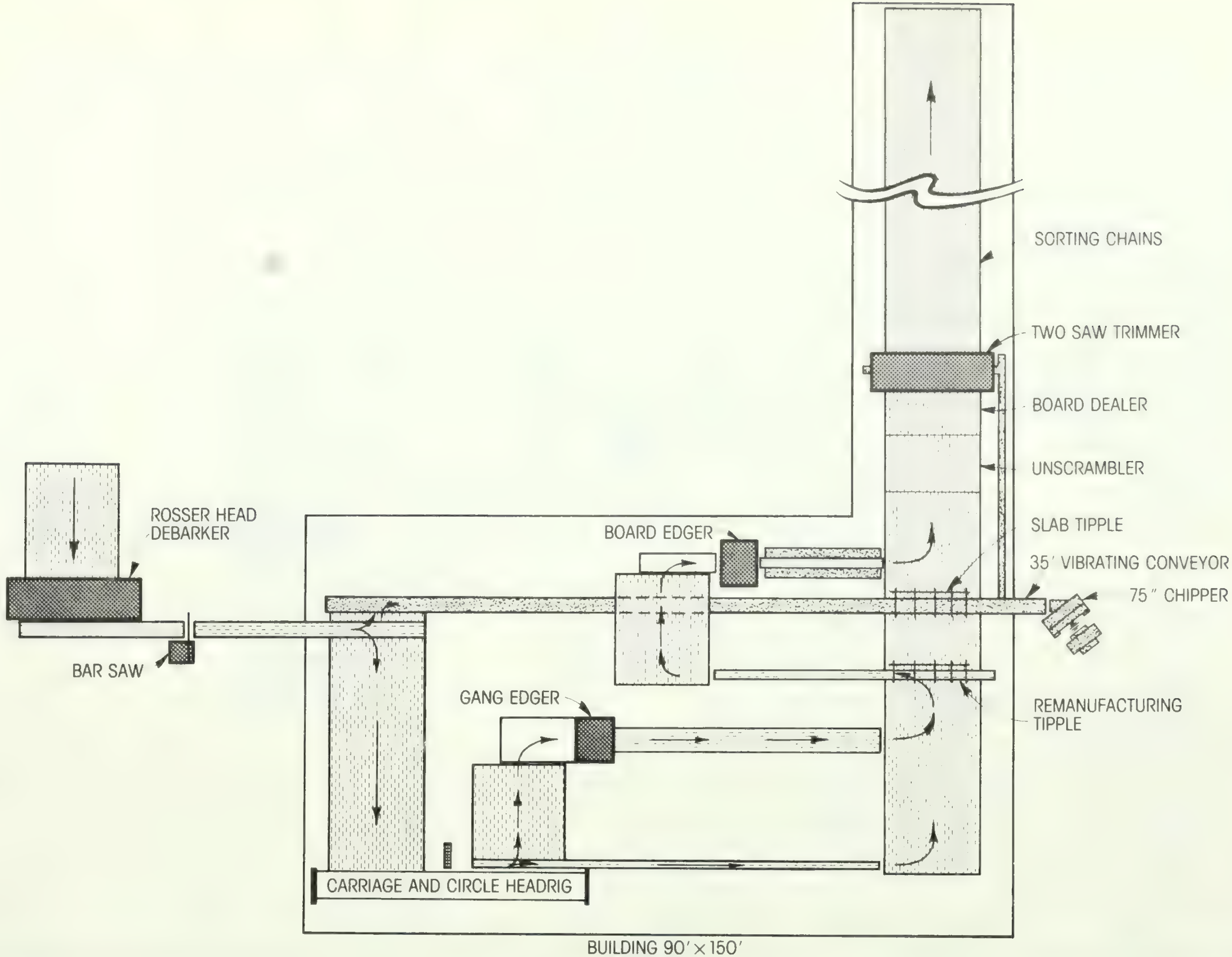


Figure 2.--Sawmill layout 2.

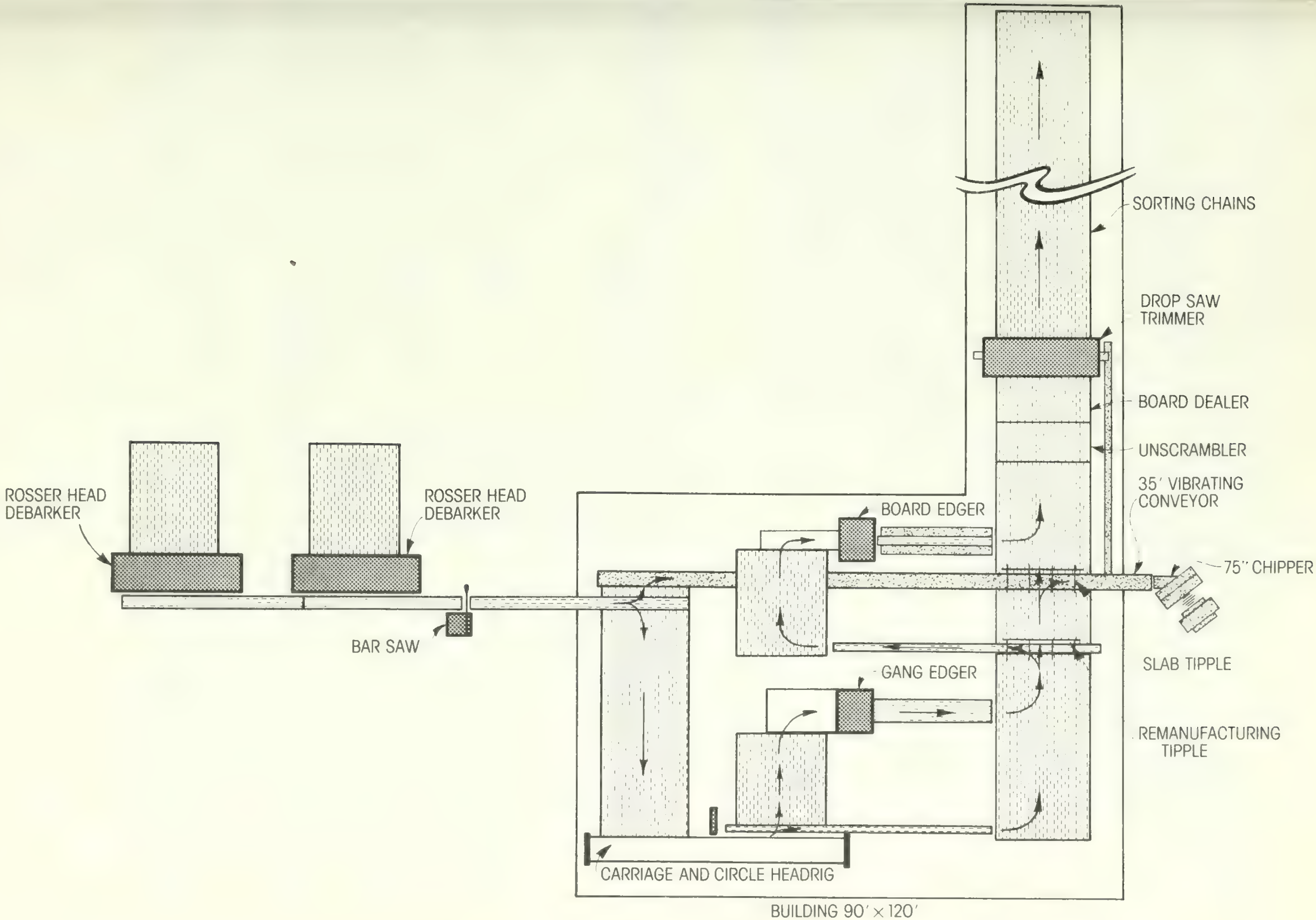


Figure 3.--Sawmill layout 3.

mill would exceed $1.7 million, would produce sales in excess of $2 millio and operating expenses of $1.5 million.

This mill design provides an improved return-on-investment based on increased production at approximately the same capital costs as Mill 2. Tl mill does not require sophisticated maintenance, but it does require logs 10 in and larger.

MILL LAYOUT #4 - BAND MILL LAYOUT

This fourth mill layout is the first shown using a band headrig and line-bar resaw (fig. 4). It is difficult to justify a bandsaw filer for a small hardwood sawmill. This is also the first mill layout designed primarily for grade lumber production. We would use this equipment only for logs over 12 inches in diameter, and would anticipate average lumber value to increase $10/M bd. ft. compared to the previous circle mill with single-arbor gang edger.

Construction of this mill would cost about $1.8 million. Sales would be approximately $2 million for production of 11 million board feet annual Operating costs of $1.4 million annually provide this mill with a competit return-on-investment.

This mill layout is more common of the northern fine hardwood mills. It is a grade mill and, therefore, profitable only with a grade log resour The equipment in this mill requires better maintenance than the previous layouts, but provides some of the best lumber available.

MILL LAYOUT #5 - CANTER MILL WITH CARRIAGE

This last sawmill layout represents a canter with a band headrig, line-bar resaw and circular gang edger (fig. 5). This mill is similar to our Franklin sawmill.

This layout utilizes a ring debarker for straight hardwood logs and a rosser head for poor quality logs, and combines breakdown of grade and low grade hardwood logs in large quantities. It is a sophisticated installation typically constructed only by large integrated companies in the East. It combines the ability to saw for grade and efficient utilization of smal logs, but the log resource must be properly balanced to the design capacit of each.

The Canter mill is estimated to cost in excess of $3.9 million but ha a production capacity of 40 million board feet annually. Operating costs would exceed $4.7 million on yearly sales of $7.1 million. The return-on-investment is competitive with the other four mill layouts discussed.

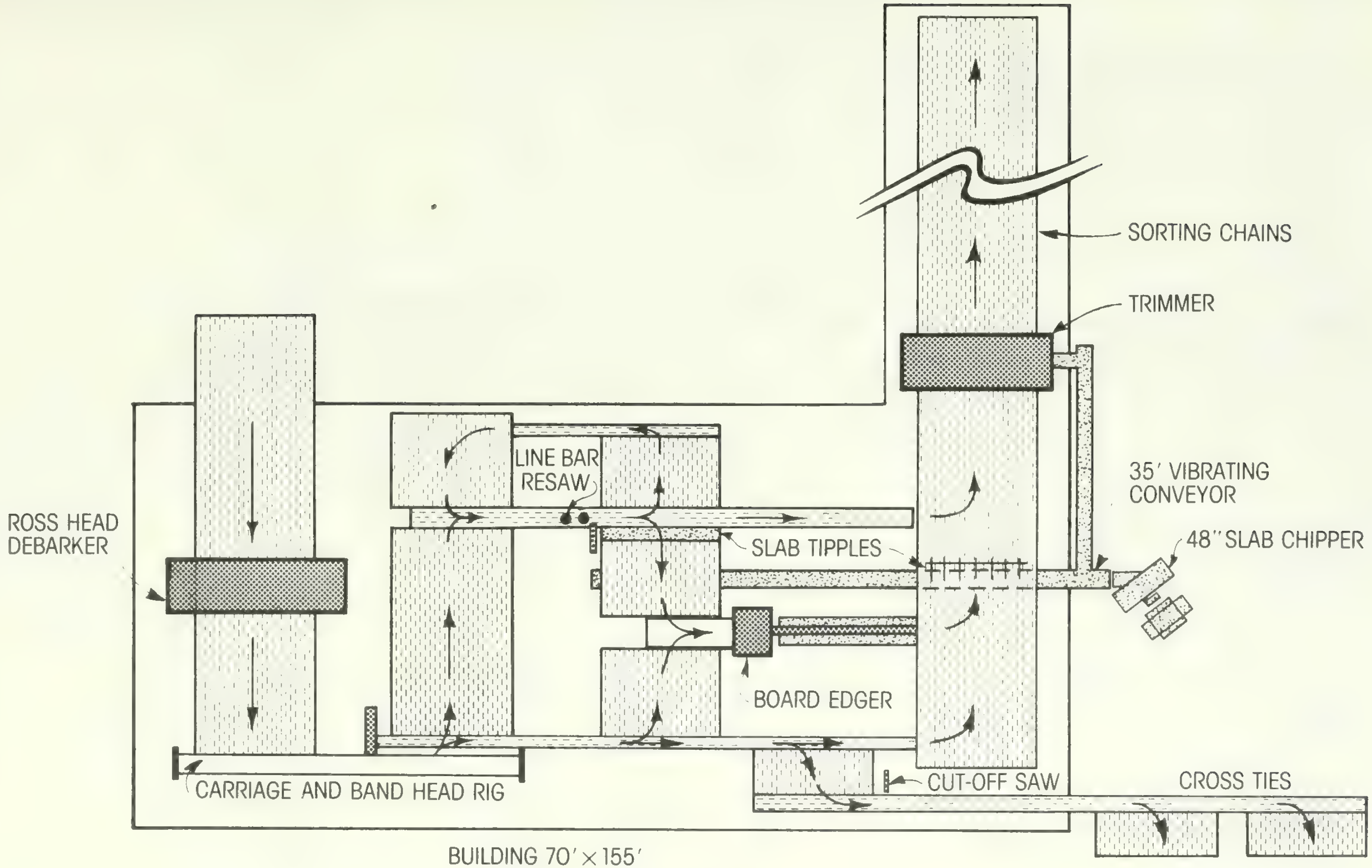


Figure 4.--Sawmill layout 4.

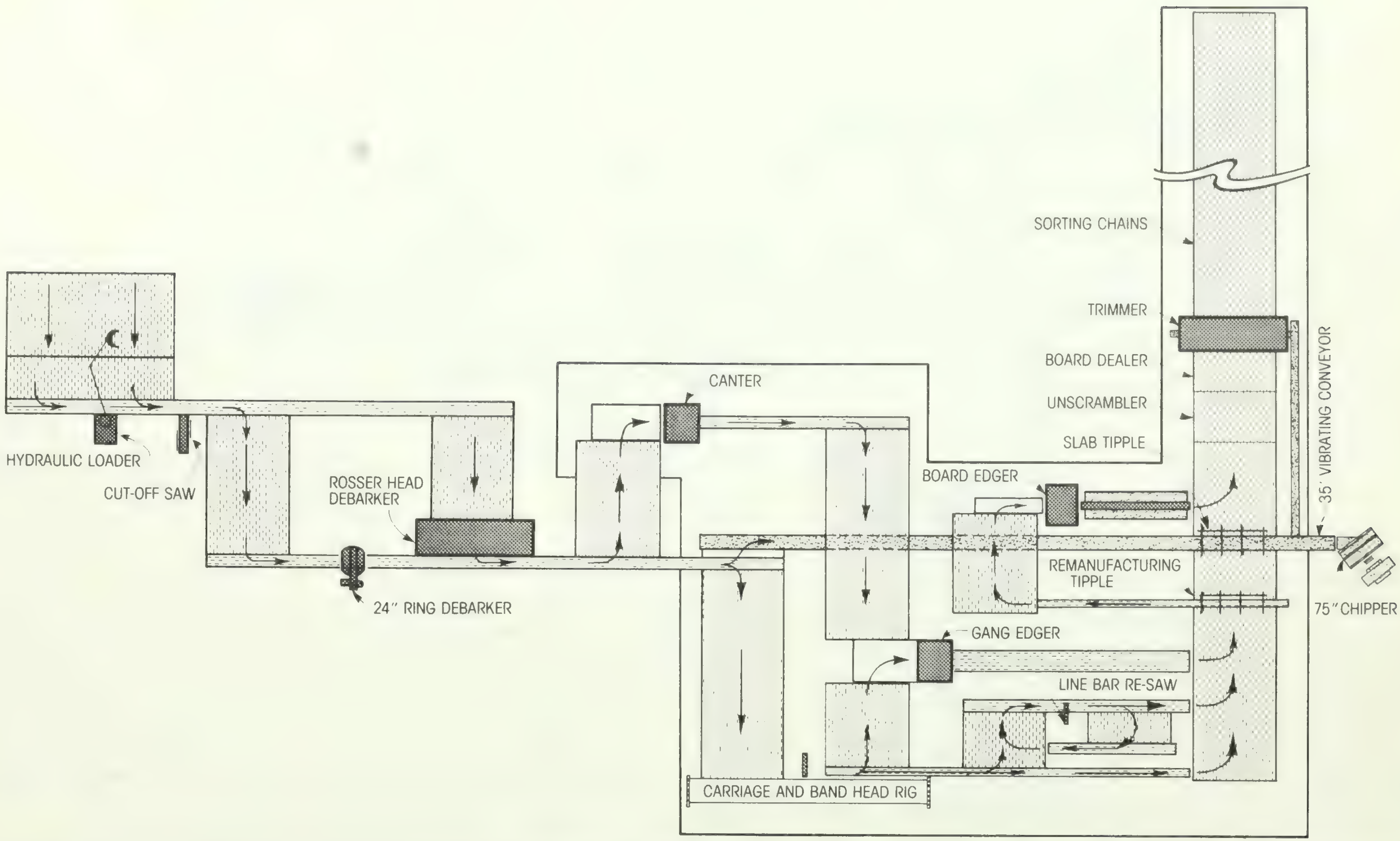


Figure 5.--Sawmill layout 5.

Basic Design Guidelines

It has been my experience that several basic principles of mill design should be continually reviewed.

1. Hardwood logs are not straight or predictable. A cut-off saw on the log deck is recommended even for log length mills.
2. Ring debarkers cannot handle all of the hardwood sawlog resource. A means of bypass is required for bad logs.
3. Double arbor gangs are designed to manufacture low grade cants into log grade lumber. The step-face from the double arbor often necessitates surfacing low grade lumber before sale to pallet manufacturers. The single-arbor edger serves well in many applications.
4. Production capacity is a function of mill design, but the mill design must first be a function of sawtimber characteristics.

Future of Hardwood Mills in the East

A year of trying to decide what Union Camp should do to better utilize its hardwood resource has not yielded any startling conclusions. I, however, hold the following points to be highly important.

1. The industry must adapt to the changing timber resource.
2. The industry will not grow substantially until rates-of-return justify higher capital investments.
3. Small independent hardwood sawmills will be replaced by large integrated firms attempting to better utilize timberland assets. Even so, the lack of market growth and the variable earnings history of hardwood operations will discourage many corporate investors.

Conclusion

I have appreciated the opportunity to present my opinions today. I would like to commend you for attending and participating in this Conference for it demonstrates your willingness to explore new alternatives for hardwood lumber. Changes are coming, and only those who are thoughtfully prepared will survive.

NEW APPROACHES TO PRODUCING FURNITURE COMPONENTS FROM HARDWOOD LUMBER

SANDY MULLIN
Barr-Mullin, Inc.
Raleigh, North Carolina

ABSTRACT

Furniture dimension parts are currently being manufactured from red alder on both the East and West Coasts. Species characteristics and the location of standing timber give alder certain competitive advantages. Dimension manufacturers, however, must continue to use every means to reduce the unit costs of processing. This paper described mini-computer systems presently being used in furniture dimension plants to reduce lumber waste.

ALDER: ONE OF TOMORROW'S IMPORTANT STRUCTURAL RAW MATERIALS?

T. M. MALONEY, Head
Wood Technology Section
Washington State University
Pullman, Washington

ABSTRACT

Alder is a lightweight, fast-growing species ideally suited for composition board and composite materials. Studies indicate that there will be a shortage of conventional raw material for plywood building materials in the Pacific Northwest. The composite panel made of veneer faces and a particleboard core offers a building panel that can possibly use alder for core. Plywood plants can maintain or increase their production rate using particleboard cores, thus avoiding problems associated with shortages of conventional veneer.

Demonstration alder flakeboards (a type of particleboard) showed excellent modulus of rupture, modulus of elasticity, and internal bond properties which exceeded those in competitive flake-type boards. Indications are that alder merits serious consideration as a raw material for structural panel materials (composition board and composites).

Introduction

Alder has long been used for a number of wood products. It has not, however, been an important structural product. In this paper I discuss the need for additional wood-based structural products, research and development programs underway for developing such new products, and the potential for alder as the raw material.

Until recently, a wealth of forest-based housing materials has been available to the people of the United States. Shortages in new housing materials are forecast for the future. Documentation backing the need for new housing materials can be found in: "Report of the President's Advisory Panel on Timber and the Environment" prepared by a 1973 select Presidential Advisory Committee (*1*), a 1973 Forest Service report "The Outlook for Timber in the United States" (*2*), and a study by the Committee on Renewable Resources for Industrial Materials, The CORRIM Report (*3, 4*). Housing is and will continue to be a critical national need relating to the general welfare of

people. It is, therefore, encumbant upon those involved in the forest prod ucts industry to provide the quantity and quality of materials for proper housing the people of the country.

Many programs are in operation to improve the growth of timber and to improve the utilization of the harvested forest. The best approach for immediate action is better utilization. With this approach forest and mi residues and smaller trees and previously unused hardwood forests could be better utilized. The impact is to be made in developing new wood material from these raw materials.

Research and Development Programs

Researchers are thoroughly studying the problems and properties of a new family of manmade structural wood materials involving particleboard co and solid wood facings and called Com-Ply®. Studs have been made using this concept, and they appear to be economically viable. This paper, however, will concentrate on the composite panel products in which alder can readily fit. This type of product can use approximately 90 percent of the whole tree rather than the approximate 1/3 now going into plywood type pro ucts. Tree species not now considered useful in the forest inventory, pa ticularly as they relate to construction products, can be included.

Successful development and marketing of such products will provide mu more additional building material for use and will also reduce the level o imports necessary to keep our expanding population, in terms of those esta lishing new households, adequately sheltered.

The research and development efforts have been underway for several years. This is particularly important to the Pacific Northwest as the siz and quality of the timber available for the production of plywood diminish W. D. Page (5) in his background paper for the Third World Consultation on Wood-Based Panels described the reduction in the amount of "conventional" peeler logs available for plywood production. There is the further proble of our shrinking forestland base while population and economic growth continue upward. Thus, with the timber supply problem there is both an economic and a social problem involved in supplying housing to people; consequently, the research efforts now underway are directed where they will ha the greatest immediate impact; namely, materials for housing.

Basic building materials such as lumber, plywood, and particleboard have been or are currently being produced from alder. Two particleboard plants operated in the State of Washington in the 1950's using alder--name the Columbia Hardboard plant in Everett and the Nu-Ply plant in South Benc The composite products as described earlier appear to have a great potenti when the use of alder is considered. In simple terms, these composite prc ucts consist of a particleboard core and veneer faces. At the present ti a product of this nature is being produced by the Potlatch Corporation in Lewiston, ID. The particleboard core is made of flakes which are aligned in one direction. Aligning the flakes greatly increases the bending and

modulus of elasticity properties so that the particleboard is approaching the levels found in veneer. The final product is made similar to plywood with the aligned flake core running at right angles to the grain of the veneer faces. Thus, the product is very similar to plywood but at the same time core voids which can cause many problems are eliminated.

Within reason, the species is secondary; however, each one may have some attributes or negative factors which have to be considered. The main consideration is whether the job can be done in terms of performance. The building products are being considered as materials, and species is not the dominant factor governing properties. Instead, engineering characteristics in terms of performance are of most importance.

The composite product already manufactured by Potlatch is approved for use in the marketplace. It is actually performing as a type of plywood and is selling at plywood prices for sheathing applications. Potlatch has performed extensive research and development getting their product into the marketplace and has essentially opened the door for others so interested. The U.S. Forest Service, the American Plywood Association, and Washington State University are at the present time cooperating in a large study developing more information on this type of product. In particular the research is investigating two species; Douglas-fir and southern pine; particle geometry including shavings, ring-cut flakes, and drum-cut flakes; phenol formaldehyde, urea formaldehyde, and melamine-urea formaldehyde binders; and random and aligned particle orientation. This experiment is not a complete factorial experiment as most of the effort is concentrated in the Douglas-fir species and phenol formaldehyde resin area. This information, however, which is being developed by others, will be useful for those considering using alder as the core in the composite product. The additional work required to bring alder into use will be minimized because of all the information already generated.

It should be pointed out, however, that it may not be necessary to orient or align the particles in the core for increasing bending strength and stiffness as randomly formed materials are already extensively in use for structural applications in western Europe, Australia, New Zealand, and in Canada. Some of these products, particularly the waferboard from Canada, are already moving into the U.S. markets. More information on this type of product will also be developed in the composite board study. As will be seen later, alder lends itself well to this type of product and it may be a species for serious future consideration. It should be noted that over $1 million is now being committed to this initial research and development effort, none of which is coming directly from the alder industry.

Alder as a Flakeboard Raw Material

In this paper, building panels in the form of flakeboard (a particleboard) are emphasized, demonstrating the good qualities of alder for either the entire structural panel or the core of the composite products. The Northwest, as mentioned, will be wanting more panel raw material as the

quality of the harvested forests decreases. This is very important if th west coast industry is to maintain its position in the marketplace. The west coast has been blessed with much of the good raw material for products--such as Douglas-fir, ponderosa pine, larch, etc. But if the studi are correct, there will be a short-fall of this material, in its present form, over the next 20 years.

The Wood Technology Laboratory at Washington State University as wel as other laboratories throughout the world have worked on many different raw materials for composite and composition board (particleboard/fiberboa products. These include different types of grass, coffee bean hulls, coc nut shells, reeds, palms, high-density hardwoods, and even fiberous mater from municipal refuse. Quality wood material is highly preferred for mak these types of products. Indeed alder fits many of the criteria for an e cellent species for composite and composition board products. It is fast growing, lightweight, free from significant specific gravity differences tween spring and summerwood, and easy to flake or otherwise reduce to particles. Flakes from alder have excellent particle dimensions for develop the properties necessary for good panel structural performance.

The crooked material can also be used because it is being reduced to flakes and, as mentioned previously, about 90 percent of the total wood c go into the product. Indeed, it may be possible to also include the bark without incurring significant damage to board properties particularly in composite-type product.

It must be noted that the process for making a particleboard is a we of interrelating factors; however, all of these factors which include particle geometry, resin level, resin type, board specific gravity and thickness, moisture content of the mat when being pressed, and pressing conditi can be manipulated advantageously to produce the type of panel product desired. All of these factors are well beyond the scope of this paper, but they are noted to indicate that an extensive body of scientific and technical knowledge is already available for moving alder into these types of products and accompanying markets.

To demonstrate the potential for alder a number of flakeboard panels were made according to conventional manufacturing parameters. The following tabulation lists the basic manufacturing parameters.

Flake type:	drum-cut (hammermilled) ring-cut
Resin type:	phenolic
Resin level:	6 percent (oven-dry basis)
Wax level:	1 percent (oven-dry basis)
Board specific gravity levels:	0.64 and 0.72
Board size:	0.500 by 12 by 15 in

As can be seen two types of conventional flakes were made. Standarc flakers were used for the flake preparation. The drum-cut flakes were nominally 0.015 in thick by 1.5 in long. Drum cutting flakes usually res

in a relatively wide flake which must be split into narrow widths for board production. This was accomplished by hammermilling the flakes without a screen mounted in the hammermill. The ring-cut flakes were nominally 0.015 in thick by 0.750 in long.

Some of these flakes were not dried immediately and this resulted in some oxidation. This is shown in the familiar orangish color of green alder that has been exposed to the air. Potential problems with gluing may result from this situation, and some boards were made with flakes that were dried immediately upon manufacture; some boards were made from oxidized flakes. It must, however, be immediately pointed out that this demonstration of board properties cannot be taken as a scientific study illustrating that there was either no problem with oxidation or vice versa. Drying of the flakes is normally accomplished immediately after cutting; this is a normal production step. The moisture content of dried flakes is nominally 4 percent.

After drying, the flakes were blended with the phenolic resin and wax in a conventional blender. The wax was included to inhibit the pick-up of water in the finished board. The blended flakes were then formed into mats and hot pressed according to a conventional schedule. The finished boards were evaluated for modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB). The modulus of rupture is a measure of the bending strength of the product. Modulus of elasticity is the property that controls the panel deflection. Deflection is the normal design parameter used with panel products. Internal bond information establishes how well the panel is glued together. The following tabulation presents information on the properties of the boards prepared for this demonstration. Figures 1-3 present this information in graphic form.

		Board Properties			
		MOR	MOE	IB	
Flake Type	Specific gravity	(psi)	(psi x 1000)	Specific gravity	(psi)
Drum-cut	0.65	4360	0.613	0.64	145
	0.72	4700	0.730	0.73	159
Ring-cut					
Non-oxidized	0.65	4160	0.601	0.65	140
	0.73	5460	0.807	0.72	178
Oxidized	0.65	3820	0.575	0.65	133
	0.63	4960	0.726	0.73	168

All of the properties found in these panels were judged as excellent for flakeboard. In comparison with commercial standard CS236-66 "Mat-Formed Wood Particleboard" (*6*), far exceed the minimum properties under consideration. These alder boards would be classified in this standard as 2B2. The minimum property requirements in this standard for 2B2 boards are as follows: modulus of rupture - 2500 psi, modulus of elasticity - 450,000 psi, and internal bond - 60 psi. A quick comparison shows all the alder board properties are far above the minimum property requirements. At the same time

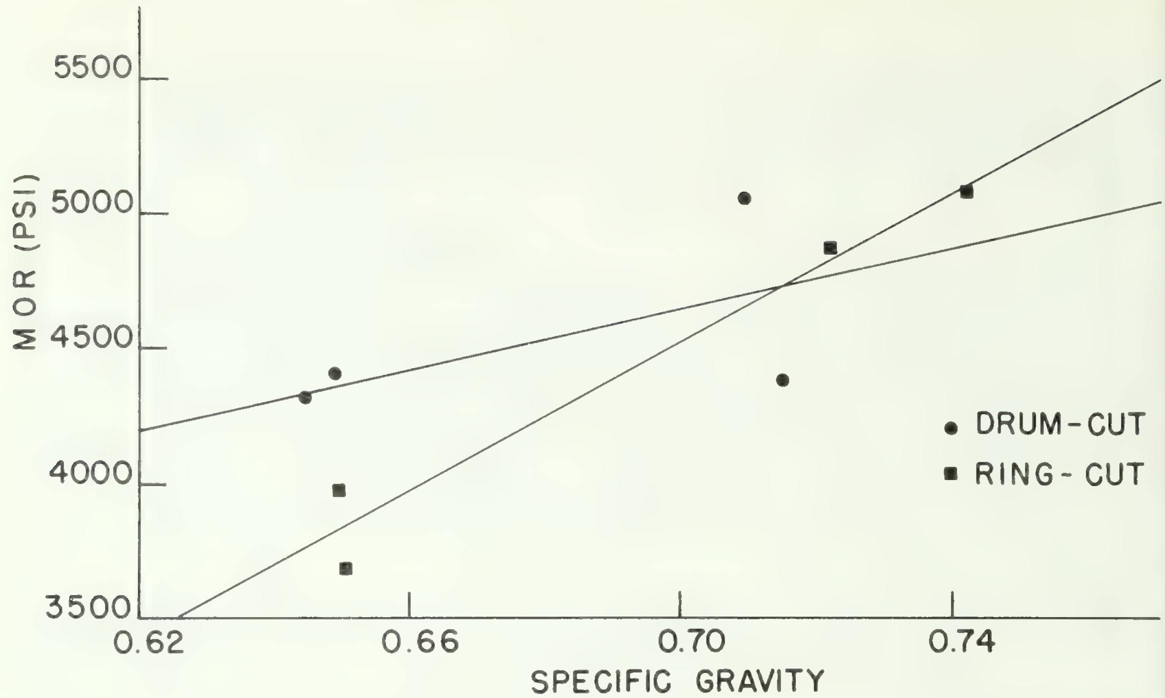


Figure 1.--Modulus of rupture vs. specific gravity for alder flakeboards.

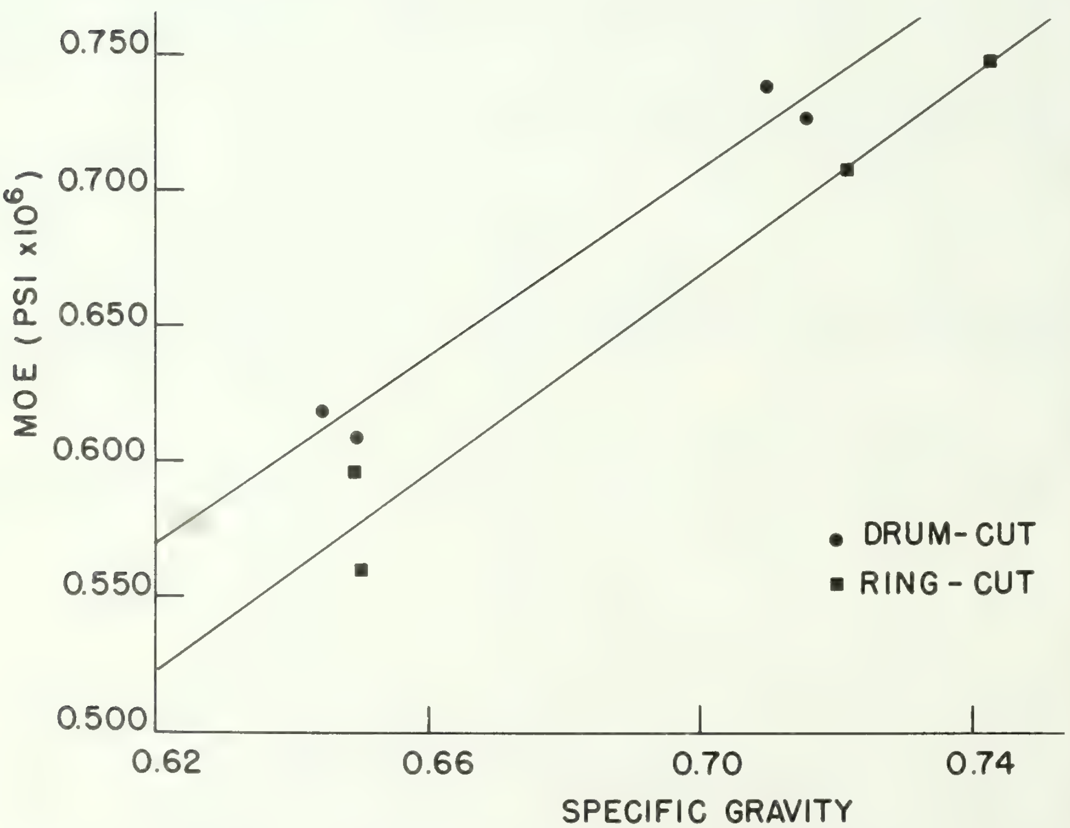


Figure 2.--Modulus of elasticity vs. specific gravity for alder flakeboards.

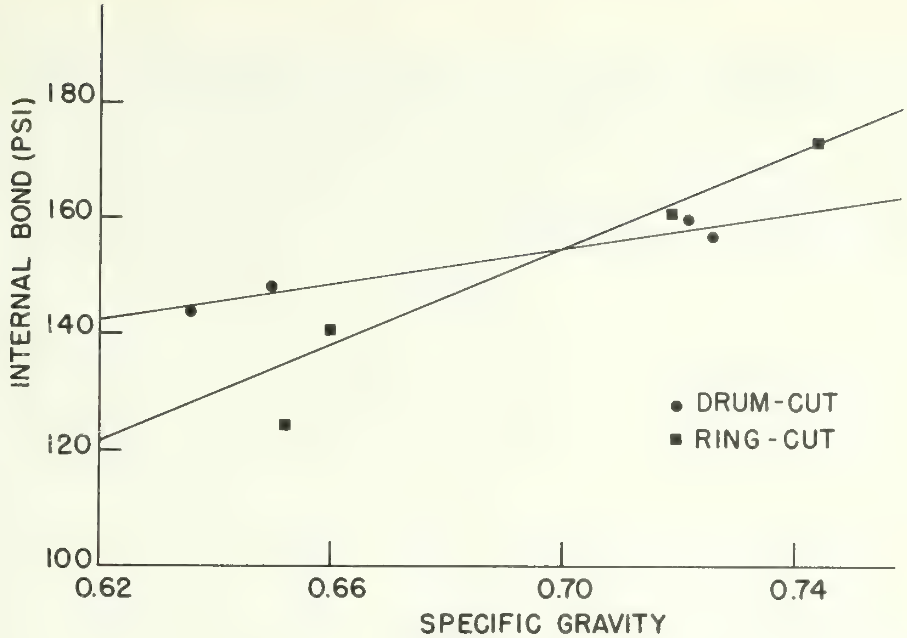


Figure 3.--Internal bond vs. specific gravity for alder flakeboards.

these properties, particularly in modulus of elasticity, are quite high even though the flakes are randomly oriented throughout the panel. A further improvement could be expected if the flakes were aligned so that the maximum bending and modulus of elasticity properties could be achieved. The properties as shown exceed those found in other flake-type products available in the marketplace for structural applications, most notably waferboard. The Canadian standard CSA Standard 0.188-1975 "Mat-Formed Wood Particleboard" (*7*) shows waferboard as having the following minimum properties: modulus of rupture - 2000 psi, modulus of elasticity - 400,000 psi, and internal bond - 40 psi.

It must be acknowledged that these standards are showing minimum properties, but field experience indicates that the demonstration alder boards have higher properties than normally found in other flakeboard-type products in the U.S. market at the present time. In fact, the properties are at such a level it would be probably possible to make lower density flakeboards than made for this presentation. This would result in the use of less wood and less resin and thus a lower cost for materials. It may be that there would be lower glue-line stresses in the composite products with the lower density alder board serving as the core between the veneer faces.

Other properties than those shown for the alder boards are needed in structural panels. Consequently, the minimum data presented here cannot be interpreted as showing alder to be acceptable for raw material in structural composition board or composite products. Based on experience and the data, however, alder has great potential for such materials. If large volumes are to be available, alder merits serious consideration, and research should be conducted using this species.

More research has to be done on the material, no matter what species is used; and, as mentioned, much of it is already in progress. Further information must be developed on the effect of the thickness density profile of

the particleboard core on composite products, the effect of density levels of the particleboard core, bonding problems due to oxidation of the wood in the case of species such as alder, durability, and the effect of particle type and size. Also needed is research on new and different binder systems. This will be important in the future as it will be impossible to make the glued type of products without new adhesive systems.

Conclusion

Alder appears to have a great possibility for use in both composition and composite-type products. It should be thoroughly appraised for consideration as a species of considerable value in future forests. The properties of flakeboards made for this presentation are excellent. The species is lightweight and easy to flake which is a great advantage. It may also be possible to use the wood and bark together particularly in the composite products. It is a fast growing species, especially through its first 20-30 years. Straight boles are not necessary for making the flakeboard products. It, therefore, should be carefully evaluated as a raw material for structural panel materials. Other advantages such as fixing nitrogen in the soil may also be of great importance in considering the use of alder as a structural raw material rather than other species which could be grown in its place, but this will have to be determined by those expert in this field.

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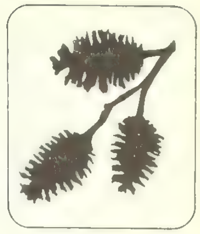
ALDER AS A WOOD FOR VENEER AND PLYWOOD



HARRY McGUANE, Owner
C.P.I. Veneers
Kirkland, Washington

Abstract

The oral presentation described the process of manufacturing alder veneer in a facility equipped with the only hardwood lathe in the West. The hardwood lathe is equipped with a fixed nose bar which is capable of achieving higher peeling pressures than conifer lathes equipped with a roller bar. The capability of achieving higher pressures is important in controlling the roughness, depth of checks, and thickness of the veneer. The end product is a dry veneer that is 1/24 inch in thickness. The majority of this veneer is used in the manufacture of quarter inch plywood wall panelling.

The market for alder veneer and its future are uncertain. Production of alder veneer has been low, and logs are frequently knotty so recovery of higher grades is difficult and costly. A large fraction is, therefore, a lower quality veneer which enters a very competitive market with surplus low quality veneers from other species. Style changes in the panelling industry and lack of familiarity with alder are other problems.

RED ALDER AS A PULPWOOD SPECIES

B. F. HRUTFIORD, Professor of Wood Chemistry
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

In this paper I discuss the use of alder as a pulpwood species. Today most alder pulpwood is procured as roundwood. Debarking of small and frequently crooked logs and storage are indicated as problems. Chips are rarely stored more than a month as they color rapidly and strength and yield losses occur. Use of alder in a number of pulping processes is discussed. Alder is suggested as the best prospect for whole tree chipping in the Northwest.

Introduction

Red alder is a useful pulpwood species in the Northwest. It can be asily pulped by the kraft or sulfite processes or by several high yield rocesses. The chemical pulp produced has the properties of a good hard-ood pulp - it is similar to the better known birch. The desirable prop-rties are good formation and good printability and texture properties such s smoothness and softness. Alder pulp, in common with hardwood pulps in eneral, has lower strength properties than softwood pulp and is blended ith softwood pulp in most uses.

Pulpwood Procurement

Most pulp mills obtain at least part of their supply of red alder from nternal sources and supplement this with some outside purchases. About 90 ercent is delivered as roundwood which is a preferred form especially if he wood is to be stored for a period of time. The wood should not be tored in contact with soil. Present prices offered for delivered pulpwood un between \$24 and \$29 per 4,800-lb unit on a bone-dry basis.

Debarking

Debarking is somewhat of a problem due to the small and frequently rooked logs and due to variation in ease of debarking. Debarking is easi-st with straight, freshly harvested logs in the spring and summer; the bark s tighter after either summer or a storage period.

The bark content is not significant for use in high yield pulping for unbleached material such as corrugating media. Up to 2-1/2 percent bark can be tolerated in kraft pulping of alder since the bark cooks out in this process. Certain NSCM[1] processes require clean chips, such as Permochem, and chips for the sulfite processes should have no more than 1/2 percent bark, preferably about 1/4 percent. Ring barkers are frequently used and are only marginal for sulfite chips; a debarker using a cutterhead which produces a fairly clean log is the best choice.

Alder Bark Use

Most alder bark is sent to hog fuel, however, one mill at least powde the bark and markets this material as a fairly successful plywood resin extender. The hardwood bark is generally more acceptable in the Northwest than similar products produced from conifer bark.

Alder Chips and Chipping

A minor amount of alder chips is purchased by the pulp mills or obtai ed internally; the present market price varies from $29 to about $40 per bone-dry ton for clean chips, the variation is due to location and shippin costs presumably.

Alder chips are not at all suitable for storage and are rarely kept more than 1 month. The chips become more difficult to pulp (delignify), a alder chips generally lose strength and also tend to produce yellow specks which cannot be removed in sulfite pulping. The chips color rapidly on storage, and yield losses of 12 percent as well as major strength losses a reported in kraft pulping of alder chips stored 6 months (*1*).

Sulfite Pulping and Bleaching

Several companies carry out acid sulfite pulping of red alder. The cooks are done batchwise with a cycle time of about 6 hours, using an init pH of about 2 and a maximum pulping temperature of perhaps 165°-170°C. Th pulp is typically delignified to a K number of 13-14 and is obtained in a yield of about 45 percent. Sulfite alder pulp is always bleached and is easily brought up to high brightness, in the 88-91 GE range. A simple chlorination (C) and high consistency hypochlorite (H) sequence produces 88-89 brightness, CEH will give higher values. Dissolving grade pulps are also produced from alder, these are made by use of a heavy alkaline extrac tion stage and perhaps a final brightening stage, chlorine dioxide (D) or sodium peroxide (P).

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[1]See glossary at the end of the paper for definitions of standard abbreviations.

A point of no small significance today is the difference between softood and hardwood spent sulfite liquor recovery. The evaporator condensate roduced during concentration of the SSL contains about twice the BOD load rom hardwood as from softwood. This is due mainly to acetic acid formed rom the much greater acetyl content of hardwoods such as red alder.

Kraft Pulping and Bleaching

Alder is also easily pulped by the kraft process. About 20 percent of oftwood chips are usually blended to produce a pulp that will run better on he machines. Pulps of K number 14 are produced in 49 percent yield in a ypical manner.

Bleaching of alder kraft pulp is somewhat more difficult than sulfite ulp, however, with sequences such as CEHD or more commonly CEHED will proluce pulps of 88-92 GE brightness. Some yield loss occurs with 90-92 percent ields across the bleach plant being typical--giving an overall yield of 4-45 percent.

The chip furnished for kraft pulping can contain more bark, perhaps up o 3 percent without any noticeable effect. Above this value dirt and pecks become noticeable and additional alkali is required to reach the same value.

High Yield Processes

The Permochem process is probably the highest quality high yield process using alder. Here a hardwood mix of about 90 percent alder is operated t an 85-86 percent yield, producing a pulp of 75 GE brightness that can be irectly used (without bleaching) in tissue. This pulp is produced by a ild sodium sulfite cook followed by a refiner, similar to refiner groundood.

Pulp Properties

The following tabulation summarizes typical handsheet properties.

	Kraft	Acid sulfite	Magnefite	Neutral magnefite
K number	13.8	13.7	13.3	20.3
Brightness	86	88	87	88
Burst[2]	117	66	81	92
Tear[2]	1.30	0.86	1.04	0.99
Tensile[2]	8,450	5,600	7,300	6,600

[2] CSF 300 ml

Pulp Uses

Bleached alder pulp is always blended with other pulps and, in additio to the uses already mentioned, is used in a variety of paper products. These uses are tissue, bond, envelope and book papers.

The Future

Red alder is the best prospect for whole tree chipping in the Northwes Such chips have a bark content of up to about 15 percent, usually with only small amounts of twigs and foliage. This amount of bark can be handled in kraft pulping but has a noticeable effect. More alkali is required, the yield is decreased, and the BTU value of the black liquor is increased. These effects are not noticeable at bark contents below 3-4 percent and much can be done to lower the bark content. Chip debarking has met with some success and screening for fines removal also is successful.

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Appendix I

GLOSSARY

BOD - biological oxygen demand.
BTU - British thermal units.
CEH - chlorination - extraction - hypochlorite bleaching sequence.
CEHD - chlorination - extraction - hypochlorite - chlorine dioxide bleaching sequence.
CEHED - chlorination - extraction - hypochlorite - extraction - chlorine dioxide bleaching sequence.
CSF - Canadian standard freeness.
GE brightness - standard brightness scale for pulps.
Kappa (K) number - measure of residual lignin.
NSCM - neutral sulfite semimechanical.
SSL - spent sulfite liquor.

RED ALDER AS A POTENTIAL SOURCE OF ENERGY[1]

NICHOLAS J. SMITH, Graduate Student
Faculty of Forestry
University of British Columbia
Vancouver, B.C.

ABSTRACT

*The energy plantation is defined and set in the Pacific Northwest energy context. Analyses on naturally established 8- to 10-year-old red alder (*Alnus rubra *Bong.) at University of British Columbia are used to demonstrate above-ground yields and energy flows. Results show a current net community productivity of 28.5 oven dry metric tonnes/ha per yr (conversion efficiencies of 3-percent visible net radiation), and a mean annual productivity of 9.0 oven dry metric tonnes/ha per yr. Possible sources of fuel by bioconversion are discussed. Fluidized-bed, combined-cycle systems have good prospects for electrical generation. To satisfy British Columbia's (B.C.) 1981 energy needs, at least 1.2 x 10^7 ha of alder plantations will be needed (12 percent of B.C.). Use will probably continue as domestic fuelwood. A market for supplements to utilities based on coal, mill waste, and forest waste may develop. In the long-term, small energy plantations for local communities in B.C. are envisaged. The term biomass farm is used preferentially since it allows flexible appropriation of yields to a spectrum of potential uses.*

The Fundamentality of Energy

When Wordsworth was relaxing on the banks of the Wye, at the inception of the Industrial Revolution, it occurred to him there was

> "...a motion and a spirit that impells
> All thinking things, all objects of all thought
> And rolls through all things."[2]

This was the poetic realization of the centrality of energy in nature. Without apothesizing the Two Laws of Thermodynamics, Schumacher (*30*) has recognized that "...energy is to the physical world what consciousness is to the human world. If energy fails, everything fails." Man has mistakenly treated

[1]The research reported here was supported, in part, by the British Columbia Forest Service Productivity Committee grant PC 006 to Dr. J. H. G. Smith.

[2]William Wordsworth: Tintern Abbey.

finite fossil fuels as energy capital leading to the dissipation of primeval solar investments to produce a state of impending fossil fuel bankruptcy. The paradox of increasing energy demands and decreasing supplies as the world population moves with an exponential alacrity to 7 billion by 2000 A.D. (*23*) is disturbingly demonstrated in gas and oil price increases of about threefold in the past 4 years.[3] Last winter's brownouts in the United States convinced many of the reality of scarcity. Not only must we look to the palliatives of new technologies and the potentials of renewable fuels, but also to basic changes in life style. The recent Carter Administration energy package (*41*) and the British Columbia Energy Commission Report (*2*) have this implication at their core.

Presently, almost half the annual world wood harvest is utilized as domestic fuel (*13*). Even in the 1880's, most North American wood was cut for this purpose. By 1970 wood provided only 1 percent of U.S. energy requirements (*19*), and in 1969 only 2 percent of Canadian needs (*4*). An impending sense of entropy has caused foresters to investigate conceptual and technical panaceas couched in terms of the complete tree concept (*45*), sycamore silage (*22*), full forest utilization (*16b*), intensive, short rotation forestry (*35, 9*), the utilization of hog fuel and forest residues (*15*), as well as bark (*7*) for energy. An additional way to increase the gross ecological efficiency of energy flows from sun via forests to man may be by the yet embryonic energy plantation.

The Energy Plantation Concept

A model energy plantation would be composed of fast grown perennials (such as sugar cane and eucalypts) and/or annuals (such as sudan grass and water hyacinths) which would feed a centrally located conversion facility producing usable energy. The objective would be "the greatest amount of biomass possible per unit time and space, at the lowest possible cost, and with a minimum of energy expenditure" (*1*). Management would be agronomic in the extremist sense. In a visionary moment the Stanford Research Institute (*1*) has outlined the operation and design as follows: "Before planting the fields would be cleared of weeds by application of a herbicide to eliminate competition for water and plant nutrients. Planting the biomass crop can be combined in one operation with application of fertilizer. At an appropriate interval after planting, a single dressing of fertilizer would be applied. The biomass crop would be harvested by means of a self-propelled combine which would chop the biomass to small pieces to facilitate drying. Aircraft would apply insecticides and fungicides when and where needed... Irrigation water would be applied at two-week intervals... The plantation would be operated seven days per week, 12 hours per day."

Such management of short rotation forests solely for energy yields was conceived only as recently as 1972 (*39*). At a time of petroleum scarcity, the idea offered a way to circumvent The Organization of Petroleum Exporting Countries domination of world economy. This nascent idea was included in a U.S. Government report in 1972 (*25*).

[3]Canadian oil prices: late 1973 - \$4.20/bbl, 1977 - \$10.60/bbl delivered to refinery gate. Canadian nat. gas prices: late 1973 - 31¢/Mft^2, 1977 - \$1.0/Mft^3, wholesale prices delivered to utility. Data supplied by B.C. Energy Commission May 6, 1977.

Since that time, several detailed feasibility studies have been under- ken. It has been presented as a favorable energy option by Evans (*11*) in e Pacific Northwest by the Stanford Research Institute (*1*) and the Inter- chnological Corporation (*40, 39, 42*)--both for Southern U.S.A., and by P.R. Associates (*29*) for Vermont using existing resources. More critical e the findings of the Northwest Energy Policy Project team (*20*) for Wash- gton, Oregon, and Idaho, Mitre Corporation, and Georgia-Pacific (*14*) for e U.S.A., and the Canadian Forest Service (*6, 28*) for Canada. Higher onomic uses of biomass, inadequate yields, and the amount of land required e among the major problems.

Red Alder and Energy

Research into potential energy crops in the Pacific Northwest has now ystallized on red alder. Alder has many attributes which give it perfect el plantation qualifications: rapid seeding after land disturbance, intenance of high densities, extreme light tolerance, full utilization of owing season, ability to coppice, improvement of soil fertility, and rel- ive disease and pest resistance. In addition, work by Smith (*31, 32, 33*), Bell (*8*), Smith and De Bell (*35*), and Zavitowski and Stevens (*45*) have monstrated the high biomass attained in natural stands. This research dicated productivity between 26 and 30 oven-dry tonnes/ha per yr in young ands. Growth rate was thought to peak between 8-15 years. Verification Smith and De Bell's work was, however, necessary since their data were sed on small (2 m^2) plots and are thought to overestimate the upper limits biomass (*34*). In addition, Zavitowski and Steven's research failed to cognize the effect of different stand densities within fully stocked nditions.

OMASS AND PRODUCTION OF RED ALDER AT
IE UNIVERSITY OF BRITISH COLUMBIA

The Area and Methods

The University of British Columbia campus lies in the Coastal Douglas- r wet subzone on podsolic soils developed over glacial debris. The alder ands sampled have developed naturally after total land clearing for road ilding and housing construction and were 8 to 10 years old. In order to etermine the conditions controlling biomass production, eight 0.04 ha uare or rectangular plots were established in July 1976 in fully stocked ands over a range of stem densities. Oven dry weight, biomass, and net roduction multiple regression equations were based on data derived from 10 mple trees from each plot, applied to the median tree on each 2-m^2 subplot d multiplied by the number of live trees per subplot to give the results table 1. In addition, subsamples were taken through late summer and fall determine the caloric content of red alder ecosystem components using mb calorimetry. These data were tested by analysis of variance and Duncan's ltiple Range Test (table 2). Plots were also systematically sampled for sser vegetation (table 3). A more detailed description can be found in nith (*37*).

Mean Measurements

Table 1 ranks mean measurements, above ground biomass, and current productivity by number of live plus dead stems and site class. The number of live stems increases from 8,000 to 43,000 stems per hectare (s.p.h.) on good and medium sites but falls off markedly on the poorer site to 13,000 s.p.h. further reflecting lower site capacity. The number of dead stems increases with increasing stand competition from 5,000 to 17,000 s.p.h. Mean measurements display a diminution with increasing density in terms of crown width, root collar diameter, d.b.h., and height. The basal area is higher on the good sites (26 m^2/ha for plot 2) and lower on the poor site (10.76 m^2/ha for plot 8) although the pattern of variation between these extremes is not clea

Biomass

Above ground biomass shows a mean value of 82 000 kg/ha giving a mean annual productivity of 9 000 kg/ha per yr. Smith's speculations (*31*) of a maximum of 60 000 kg/ha per yr are somewhat underscored, as are De Bell's estimates (*8*) of 20 000 kg/ha per yr in very dense 8- to 11-year-old alder. It is interesting, however, that the maximum subplot record of 376 000 kg/h would indicate that over small areas 41 000 kg/ha per yr is achieved and ma represent the management paradigm under these conditions. The most productive plot yielded 12 000 kg/ha per yr. To what extent intensive management can improve upon this remains speculative--I would suggest 15 000 kg/ha per yr as a conservative estimate. This compares with black poplar (*Populus trichocarpa* Torr. Gray) grown in the Pacific Northwest which may achieve 12 000 kg/ha per yr on 2- and 4-year cutting cycles (*9*). Because of a mix of collection, storage, and environmental reasons as well as other potential uses, leaves and reproductive organs should be excluded, thus decreasing biomass yields going to the fuel plant by 8 percent. The most dense stands have an unexpectedly high branch biomass. Although relative weight of branches per tree is smaller in dense plots (canopies are not yet discrete), much ingrowth is incurred giving greater absolute branch biomass.

Productivity

The current productivity between 8 to 10 years does not include a statement of loss to mortality or insect consumption over the growing seaso in order to define what Odum (*26*) called net community production. Growth in this age class may be entering the exponential phase with an average of 28 600 kg/ha per yr. Westlake (*43*) recorded maxima of 33 000 kg/ha per yr production in temperate perennial crops. These data confirm red alder's repute as a high yielding species. Current productivity is greatest in the more crowded stands, indicating that intense competition may delay the inflection point for production till a later age.

Ecological Data

Table 4 lists ecological data based on table 1. The biomass accumulation ratio is greatest in the more open (by total trees) stands (3.37 in the most open to 2.6 in the most dense), and also reflects decreasing productiv-

Table 1--*Mean measurements, above ground biomass and net production for 8-10-year red alder ecosystems at University of British Columbia (averaged per 0.04 ha plot)*[1]

Component Analyses	Plots ranked by density (live plus dead trees) and site									
	1	2	3	4	5	6	7	8	Average	Maximum[3]
Mean measurements[2]										
Number of live stems/ha	8,204	8,871	9,983	15,790	22,264	42,971	17,025	13,047	17,103	96,370
Number of dead stems/ha	5,239	3,435	9,142	11,737	16,729	16,729	6,079	1,169	7,169	46,950
Site class	G	G	G	M	M	M-P	P	P	M	--
Rcd (cm)	8.3	6.8	5.3	5.6	4.75	3.4	4.6	4.5	5.4	15.7
D.b.h. (cm)	6.0	5.5	4.4	4.6	3.5	2.6	3.6	3.4	4.2	12.2
CW (m)	3.2	2.0	2.1	1.9	1.6	1.1	1.4	1.6	1.9	4.9
Ht (m)	9.9	9.4	9.4	8.1	7.4	6.1	6.1	5.6	7.8	14.0
BA (m^2/ha)	25.6	26.0	17.8	23.5	19.01	20.48	20.2	10.76	19.6	76.5
Biomass (dry kg/ha)										
Total	96,922	92,517	67,631	112,027	82,883	106,883	58,372	39,640	82,128	366,639
Stem	62,347	57,124	42,817	73,016	42,902	54,528	32,134	21,926	48,349	229,894
Stem bark	10,028	9,603	7,291	12,381	9,290	13,070	6,990	4,892	9,193	34,718
Leaf	6,579	7,325	5,230	7,961	6,672	7,083	4,677	3,032	6,070	26,646
Branches	17,572	18,058	12,022	18,258	23,305	30,710	14,332	9,484	18,030	73,322
Reproductive organs	396	407	271	411	714	942	439	306	486	2,109
Current productivity (dry kg/ha per year)										
Total	28,737	28,015	20,029	32,315	35,952	40,831	25,125	17,802	28,601	117,420
Stem	14,531	12,793	9,301	15,803	18,701	19,347	13,863	10,134	14,309	57,464
Stem bark	1,505	1,442	1,095	1,860	1,393	1,960	1,049	733	1,380	5,214
Leaf	6,579	7,324	5,230	7,961	6,672	7,083	4,677	3,032	6,070	26,646
Branches	5,725	6,049	4,131	6,280	8,472	11,499	5,097	3,597	6,356	25,987
Reproductive organs	396	407	271	411	714	942	439	306	486	2,109

1/ Rcd = root collar diameter; CW = crown width.

2/ Site class G = over 27 m at 50 years; M = 18-27 m at 50 years; P = below 18 m at 50 years (based on Worthington et. al (*44*)).

3/ Maximum for a single subplot (2 m^2).

Table 2--*Caloric values in 8-10 year red alder ecosystems--spatial and temporal flows (calories/gm, three replicates)*[1/]

1. SPATIAL

A. Overstory

July ($\bar{x}$ = 4636.1 ± 300.4)

Roots	Stem d.b.h.	Stem top	Stem base	Old cones	Catkins	Branches	Leaves	Bark base	Bark d.b.h.	Twigs	Strobiles	Bark top
4229	4399	4402	4406	4415	4534	4585	4752	4758	4787	4824	5068	5314

September ($\bar{x}$ = 4640.2 ± 226.3)

Strobiles	Stem d.b.h.	Roots	Branches	Bark d.b.h.	Leaves	Twigs	Catkins
4362	4438	4450	4537	4736	4748	4758	5065

November ($\bar{x}$ = 4712.8 ± 229.2)

Roots	Stem d.b.h.	Strobiles	Branches	Bark	Twigs	Leaves	Catkins
4382	4429	4547	4692	4833	4883	4898	5037

B. Understory

($\bar{x}$ = 4267.6 ± 269)

Ferns	Mosses	Herbs/Grasses	Rubus current	Rubus old	Conifer seedlings
3996	4080	4145	4209	4422	4755

C. Ground Layer

Humus	Litterfall
4517	4976

2. TEMPORAL (All three months)

($\bar{x}$ = 4668.8 ± 240)

Roots	Stem d.b.h.	Branches	Strobiles	Bark d.b.h.	Leaves	Twigs	Catkins
4354	4422	4605	4659	4785	4799	4831	4879

[1/] Line joins homogeneous subsets (Duncan's Multiple Range. α = 0.05).

Table 3--*Understory above ground biomass and net production for 8-10 year old red alder ecosystems*

Item	Plots ranked by (live plus dead trees) site								
	1	2	3	4	5	6	7	8	Average ± $S\bar{x}$
s (dry kg/ha)	3 241	1 944	124	296	2 471	583	593	790	1 255±399
t of overstory s	3.0	2.0	0.1	0.3	3.0	0.5	1.0	2.0	1.5
ion g/ha per yr)	1 374	759	118	144	1 199	397	442	294	591±170
t of overstory tion	5.0	3.0	0.5	0.4	3.0	0.1	0.1	2.0	2.0

r poorer quality sites. The leaf area index measures photosynthetic tivity. Increasing leaf area means increased productivity potential. reater leaf areas are associated with the denser stands and more productive tes (10.02 in plot 4 as against 3.81 in plot 8). Foliage assimilation ef- iciency expresses net production in terms of leaf weight and shows that, for given site class, with increasing stand density, greater leaf production fficiencies are attained. One explanation may be greater noctural buildup f CO_2 in the dense stands giving them a photosynthetic premium over the ore open conditions. The standing crop density index has been used by Kira nd Shidei (*17*) to characterize the three dimensional arrangement of forests. t gives the apparent density of the standing crop. The denser stands ccupy total space more effectively with an index of 1.74 in plot 6 as gainst an average of 1.06.

Table 3 shows above ground understory biomass and net production as .5 percent overstory biomass and 2 percent overstory production. The ajor reason for this small contribution is the intense shading. In the ore open plots understory biomass and production is greater. Plot 5 has n unexplained high understory biomass for its density.

Table 2 gives the caloric value of ecosystem components. Results show hat significant variation exists between parts of a tree and also over ime. The last line in the table shows that over time (July, September, and ovember) a certain amount of fidelity exists between roots and stems, and hen between bark, leaves and twigs, with branches forming a separate sub- roup. Catkins and strobiles are, however, more variable over time as is hown by their ranking within each month.

Solar energy conversion efficiency for alder was derived from these ata (see table 5). Above ground net primary productivity estimates for 8- o 10-year-old alder stands represent conversion efficiencies of 1.5 percent or net radiation and 3 percent for photosynthetically active radiation (PAR). hus, alder appears to be one of the most efficient converters of sunlight n the Northern Hemisphere. Westlake's data (*43*) show that 3 percent PAR pproaches the maximum attainable upper limit in temperate zones. If the verage wood production over the life of the stands is, however, taken at 000 kg/ha per yr, conversion efficiencies are 0.5 percent net radiation nd 1-percent photosynthetically active radiation.

Table 4--*Ecological data for 8-10 year red alder ecosystems at University of British Columbia*[1/]

Item	Plots ranked by (live plus dead trees) site								
	1	2	3	4	5	7	7	8	Average
B.A.R. (kg/kg)	3.37	3.30	3.38	3.47	2.30	2.60	2.30	2.23	2.75
L.A.I. (m^2/m^2)	8.28	9.22	6.59	10.02	8.40	8.92	5.88	3.81	7.64
F.A.E. (kg/kg)	4.37	3.82	3.83	4.06	5.30	5.76	5.37	5.87	4.90
S.C.D. (kg/m^3)	.98	.98	.72	1.39	1.11	1.74	.96	.71	1.06

[1/] B.A.R. = Above ground biomass accumulation ratio: (biomass/net production).
L.A.I. = Leaf area index: (leaf wt/m^2) x (surface area/kg or 12.59 m^2/kg for red alder).
F.A.E. = Foliage assimilation efficiency (net production/leaf weight).
S.C.D. = Standing crop density index: (standing biomass (kg/m^2)/average height standing crop (m)).

Table 5--*The solar energy conversion efficiencies of red alder at University of British Columbia between 8-10 years (Average of eight 0.04 ha plots)*

A. Invested energy	Above ground NPP[1/] kg/ha	Caloric value of component K cal/kg	Energy budget K cal/ha	Percent distribution
Stem wood	$1.4x10^4$	$4.4x10^3$	$6.2x10^7$	47
Stem bark	$1.4x10^3$	$4.8x10^3$	$6.6x10^6$	05
Branches	$6.4x10^3$	$4.6x10^3$	$2.9x10^7$	22
Foliage	$6.1x10^3$	$4.8x10^3$	$2.9x10^7$	22
Reproductive organs	$.5x10^3$	$4.7x10^3$	$2.3x10^6$	02
Understory	$.6x10^3$	$4.3x10^3$	$2.5x10^6$	02
Total	$2.9x10^4$		$1.3x10^8$	
B. Incoming energy (Kcal/ha)				
Net radiation (mean April-October 1974-1976)			$8.9x10^9$	
Visible wave length (50 percent net radiation)			$4.5x10^9$	
C. Efficiencies				
Net radiation			1.5 percent	
Visible wave length			3.0 percent	

[1/] NPP = net primary production.

Thus, although previous estimates have not been fully substantiated, red alder remains one of the most productive trees in the Pacific Northwest over short time horizons.

Methods for Converting Red Alder to Energy

Table 6 lists some of the techniques for deriving as much of the stored nergy as possible for human use. Table 7 shows the weighted energy value f alder in comparison to other fuels. The biggest bane which militates gainst the use of wood fuels is the moisture content which engenders caloric owngrading, both in terms of increased unit weight and heat lost through vaporation. Unlike fossil fuels, wood is renewable, has low sulphur and itrous oxide emissions, and particulate emissions can be controlled using urrent technology (*18*).

Table 6--*Some potential energy uses for red alder*

1. Carbonization (charcoal).
2. Direct thermal combustion (using steam turbines)
3. Biomass gasification/liquefaction:
   (a) Pyrolysis - low BTU gas (producer and wood gas)
   (b) Synthetic natural gas (methane)
      i. Direct - anaerobic digestion
      ii. Indirect - hydrogenation of lower energy gas
   (c) Distillation - by-products (methanol, acetone).
4. Combined cycle gasification using low energy gas.
5. Fluidized bed combustion/gasification.
6. Others, e.g., 'Muka' from foliage, slow burning wood stoves.

Table 7--*Approximate caloric value of red alder and other fuels*

Fuel	Comparative caloric value
Paraffin	10.4
Oil	9.8
Charcoal	7.1
Coal (bituminous)	6.9
Alder (oven dry)	4.6
Dung (air dry)	4.0
Alder (50 percent moisture, dry basis)	3.5

Carbonization of alder to charcoal has most relevance in developing economies (*10*) but also has potentials in specialized markets, e.g., barbecuing.

Direct thermal combustion to produce electricity has been scrutinized recently by consultants' analyses (*1, 29*). Comparative studies in Vermont (*29*) revealed wood-fired electric generating stations to be more costly tha coal- or oil-fired stations. Total costs incurred in energy production inflated to 1977 prices are 3.8¢/kwh for wood, 3.1¢/kwh for coal, and 3.2¢/kwh for oil. This was mainly due to higher capital costs for steam boilers usi wood. Presently, marketed wood-fired boilers are limited to 50 MW due to lack of demand thus limiting economies of scale (*18*). Also, high moisture content of wood reduces boiler efficiency to about 70 percent (*11*), and is much less than coal which is about 86 percent (*29*). Overall efficiencies for alder-fired 150 MW stations are calculated as 26 percent (table 8, Section A).

With the trend towards energy self-sufficiency in the forest products sector and with increased emphasis on coal and municipal refuse-based energ facilities, various technologies are being developed which set the fuel plantation in a more favorable position. One option is gasification and liquefaction by pyrolysis. Gasifier technology has been redundant since early developments in Germany because of the advent of natural gas (*3*). Water and wood are converted to CO and H_2 under high pressure and temperature in the absence of O_2 to yield low energy, clean burning gases of abou 5 K cal/m^3.

Methane or sythetic natural gas may be produced directly by anaerobic digestion of wood or by hydrogenation of low energy gases. To get the correct 4:1 ratio of hydrogen to carbon, the conversion process requires 1 steps for wood yet only 4 steps for natural gas, thus making the process wi wood three times as expensive (*11*).

Wood alcohols may be produced by dry distillation to yield methanol, a by acid hydrolysis to yield ethanol. Alcohols have great potentials as gasoline additives since they reduce pollutant emissions and allow higher compression ratios (*6*).

Combining gasification systems with conventional steam turbines under pressurized conditions gives improved efficiences which more than cancel ou the high production cost of low energy gases. According to a recent report by British Columbia Hydro (*3*), two-thirds of the heat input to gas turbines may be rejected as waste heat. This heat may be utilized under a steam cycle to generate power at 20 percent efficiency. Even with such a poor steam cycle efficiency, the combined cycle net efficiency may exceed 40 percent. Prospects of 45 percent are envisioned using 1990 technology. Us this system, we can assume that wood will achieve similar efficiencies to c due to more complete gasification.[4]

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[4]Dr. R. Woodley. Research Scientist. British Columbia Hydro and Power Authority Pers. Comm. May 4, 1977.

Table 8--*Energy efficiencies and land requirements for biomass fueled 150-MW generating plants*

. Plant efficiencies using direct combustion

$$\text{Station Heat Rate (SHR)} = \frac{\text{Net Heat Rate of Turbine (NHR)}}{(1 - \text{auxilliary power}) \times \text{boiler efficiency}}$$

NHR = 2 080 K cal/kwh at 60 percent peak load

$$\text{SHR} = \frac{2\ 080}{(1 - .09) \times .7} = 3\ 265 \text{ K cal/kwh}$$

$$\text{Plant Efficiency} = \frac{860 \text{ K cal (1 kwh)}}{3\ 265} = 26 \text{ percent}$$

. Energy production using direct combustion (11)

Weighted caloric value of alder (oven dry) = 4.6×10^6 K cal/tonne

@ 26 percent station efficiency = 1.2×10^6 K cal/tonne

@ 1.2×10^{-3} kwh = 1.4×10^3 kwh/tonne

1 MW yr = 8.76×10^6 kwh

1 MW needs 6.26×10^3 tonnes of alder/yr

At (say) 60 percent installed capacity 150 MW = 90 MW

90 MW needs 5.6×10^5 tonnes of alder/yr

. Land requirements for direct combustion and combined cycle-based 150-MW fuel plantations

- Area in hectares -

Yield (tonne/ha per yr) (excludes leaves)	Direct firing 26 percent efficiency	Advanced combined cycle (1990 technology) (23) 45 percent efficiency
1	$5.6x10^5$	$3.2x10^5$
8.5[1/]	$6.6x10^4$	$3.8x10^4$
22.5[2/]	$2.5x10^4$	$1.4x10^4$

). No. stations and land required to meet B.C.'s total energy needs

1981 needs (2) = $2.1x10^{14}$ K cal = $2.9x10^4$ MW

A 150-MW station contributes $\frac{2.8x10^4}{90} \approx 0.3$ percent or three hundred and ten 150-MW stations

Thus, land requirements are:

Yield (tonne/ha per yr)	Direct firing ha	Direct firing percent B.C.	Advanced combined cycle ha	Advanced combined cycle percent B.C.
8.5	$2.0x10^7$	21	$1.2x10^7$	12
22.5	$7.8x10^6$	8	$4.3x10^6$	4

[1/] 8.5 tonne/ha per yr = mean annual productivity of alder at University of British Columbia.

[2/] 22.5 tonne/ha per yr = net primary productivity between 8-10 years at University of British Columbia.

Generating power can be enhanced by replacing conventional spreader-stokers or dutch ovens with pressurized fluidized bed combustors (*1, 3, 29*
Fuel is dropped into a turbulent bed of non-combustible material such as sand--a hot gas is released which is cleansed and drives a gas turbine, th exhaust gas from which may be utilized in a steam cycle. Overall, the mix of fluidized bed combustors and combined cycles puts wood in an extremely favorable position. Variable fuel size tolerance is great, there being no need to pulverize. The Vermont study (*29*) has shown that in the use of th technique, wood is economically competitive with oil. Larger capital cost were offset by lower fuel costs and improved efficiencies. Costs were 2.6 kwh for biomass and 2.54¢/kwh for oil. Moreover, as oil, gas, and coal prices increase relative to wood, then biomass fueled combined cycle techniques can only appear more feasible.

Other alternatives include energy substitution with alder. Foliage utilization for cattle feed in the Union of Soviet Socialist Republics to produce muka (sic) (*16a*) is a current growth industry. One tonne of folia used as animal feed might release one tonne of grain to increase world foo stocks. Also, the market for slow wood-burning stoves has increased pheno enally (*6*). Presently the main use for alder in B.C. is thought to be as domestic fuel wood (*24*). Free use permits issued by the B.C. Forest Servi have encouraged this since alder is not yet regarded as a commercial speci with stumpage at $2 per hundred ft^3.

Land Base Required

I have so far totally ignored the one factor which militates against red alder fuel plantations more than any other--that of land competition f other uses.

Table 8 takes the base case of a 150-MW generating station fired by wood using direct combustion. Part A shows that with a net heat rate of 2080 K cal/kwh the net plant efficiency is 26 percent. Part B shows that a 60 percent of installed capacity the station would require 560 000 tonnes alder each year. Section C shows the land requirements based on three productivity levels under regimes of current and future technology. Section computes the land required to meet B.C.'s total energy needs by 1981. We would need approximately three hundred and ten 150-MW stations. The land required for direct firing would amount to 21 percent of B.C.at 8.5 tonnes ha per yr and 8 percent of B.C. at 22.5 tonnes/ha per yr. Even under the advanced combined cycle based on 1990 technology, the area needed would be 12 percent of B.C. at 8.5 tonnes/ha per yr and 4 percent of B.C. at 22.5 tonnes/ha per yr.

Although data are lacking for British Columbia, there are thought to exist over 300 million m^3 gross volume of red alder growing on more than 160 000 ha (*31*), much of this being poorly utilized (*24*). If this land we contiguous and brought into short rotation cycles, only four 150-MW stations could be supplied at 8.5 tonnes/ha per yr assuming future technologi Clearly, it is folly to consider supplying all our needs from fuel plantations. Allocation of land to thermal forests raises serious doubts about

highest and optimum use of land. First, alder is limited in its ecol-
gcal range to below 800 m and requires at least 60 cm rain per year (*27*).
B.C. it is restricted to the Coastal Western Hemlock-Western Redcedar
Coastal Douglas-fir biogeoclimatic zones. Second, in the light of compe-
ion of land for timber, food, and grazing, alder will be relegated to
ond best sites where productive potentials will be maimed, long term
tained yield questionable, and mechanization frustrated by terrain. More-
r, the energy plantation concept is founded on the philosophy of economic
wth. In a penetrating article entitled, "Not yet out of the woods" (*5*),
rles Calef levied the following strictures against the energy plantation.
e Schumacher (*30*), he saw the futility of societal preoccupation with
wth; Calef argued that the energy plantation is based on this principle.
is reasoned that a more appropriate technology or biotechnology is needed
ch puts man within the thermodynamic carrying capacity of the land. Calef
o questioned the environmental impact of energy plantations. In reply,
is doubtful--though still speculative--that red alder would be deleterious
this respect. If alder was grown from rootsprouts, then erosion would be
imized. Similarly, alder's inherent ability to fix nitrogen makes Calef's
bts redundant, especially if station ash is returned thus refurbishing
assium and phosphorous. By truncating the food-web from sun via alder to
, it will, however, be at the expense of flora and fauna. Thus, in the
ist sense, the energy plantation could be esthetically and ecologically
rile because they would be very dense monocultures.

Conclusion

Traditionally, accepted precepts of energy abundance have lost their
idity. The Carter Administration (*14*) and British Columbia Energy
nmission (*2*) have both stressed the need for energy conservation. The
ne has come to transfer from finite to renewable and environmentally safe
ergy sources. During the interphase period, alder grown on marginal land
ld be used to supplement coal, hog waste, and forest residue-based elec-
ic generating stations for both industrial and consumer needs. In the
ng term, as coal and mill and forest wastes decrease, alder energy plan-
tions will become more economic. But, it is unlikely that the economies
scale envisioned for eucalypts growing in southern United States (*1, 38*)
ll ever be achieved due to land scarcity. Satellite photographs show that
irly large areas of alder already exist on Vancouver Island. Small scale
ergy plantations or life support systems might be conceived growing around
cal communities, which when managed on 8- to 10-year cycles could theoret-
ally provide the total influx of energy as well as animal and human feed-
uffs, chemicals, and shelter. The term energy plantation, however, implies
market committment of biomass to energy. To avoid this inflexibility, it
y be more reasonable to rename alder energy plantations as biomass farms.
e goal would still be maximum biomass, but yields would be appropriated
the most economic and socially desirable end use, e.g., chips for pulp,
rticle board, domestic or station fuel, etc.

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DEVELOPING NEW ALDER MARKETS

R. D. BEHM, President
R. D. Behm Company
Vancouver, Washington

ABSTRACT

Attitude toward alder will play an important role in its future. Alder must be recognized as a species which produces a positive contribution to the local economy. The alder image can be improved by dropping the word "red" from its name and by promoting it as an alternate to other woods rather than a cheap substitute. The attitude of prospective buyers of alder will improve as the local industry improves delivery, quality control, and promotional efforts.

Two of the elements necessary for the successful marketing of northwest lder and bigleaf maple are indicated in the following two, seemingly unreated points. These points represent attitude, rather than product performnce or price. Without these attitudes, the 16 markets in which alder has ts best expansion opportunities cannot be consistently sold.

There has to be a positive attitude about the value of the alder and ts contribution to the local economy. State and Federal resource groups ust look at the hardwood forests, not just as a cash stumpage value but as source of community payroll which will be 300 or 400 percent in added alue. The fact that hardwoods can be harvested three or four times before softwood forest and can bring 6 to 9 times as much area payroll as softood forests more than compensates for the lower stumpage yield.

An example of the results of a more positive attitude by government and ivilian groups occurred a few weeks ago. While in the Seattle area, I eard a radio newscast which commented on the important value of northwest lder as a very desirable furniture wood. The phrasing was very similar to ews releases which we had prepared when we were getting the State of ashington Department of Natural Resources to change the definition of alder rom a "weed" species to a merchantable forest resource. The Oregon reource booklet still shows alder as an undesirable species, and this is one f the attitudes which we believe must be changed before our northwest woods ake their proper place in the major markets.

At the same time, we should officially drop the term "red" from all disussions of alder. It is not red and in fact is the most uniform light tan ood available anywhere. To the manufacturer using wood, red is just as bad s waving a red banner in front of a bull.

A second change of attitude relates specifically to almost half of th producers of alder lumber. This is the responsibility for consistent quality and consistent delivery schedules. Too many opportunists remain w make wild promises and, when the market is good, mix in some marginal boar which disappoint buyers. It is like the bad apple in the barrel, an improper grade mix, and later delivery clouds the reputation of the entire w industry.

One mid-west firm, using the term "knotty alder" for promotion, found in less than one year that it was outselling popular oak and pine suites. It took a strong selling job to get this firm to identify this hardwood, a most eastern manufacturers prefer to use "other selected hardwoods". The sales representative and mill sales manager prepared an elaborate presentation of reasons why alder would be a good sales point in the firm's promoti plans. The physical attributes were secondary to publicity articles writt by editors of trade magazines. These articles were a result of close cont with editors. For example, firms who were using alder invited the editor the plant for special conference on the firm's experience with alder. The articles proved to this furniture manufacturer that mention of western alder was a newsworthy subject, so he decided to use alder in his literatu The results have been highly successful. It is this selling in depth, bey just supplying the material, that is most important in future use of our western hardwoods.

The current trend has been to the strong character woods such as oaks, pecan, and pine. If this midwest furniture company can make a huge success of a close grain alder group, outselling his oak and pine suites, it may b an indication of a trend away from strong grained woods to the more refine and subtle wood grains.

No wood species group, nor all wood industries combined, can set a trend in style. We can, however, accelerate a trend that is beginning and probably sustain it for a few years. It becomes important, therefore, to carefully evaluate all market trends and to keep close watch on wood tones. Alder is one of the most easily stained and finished woods on the market, and if we can catch an ascending color trend such as fruitwood, we have a better chance of building our market.

Keeping in constant contact with the furniture and cabinet industry is a basic part of my work with the wood industry. I carefully evaluate all major furniture markets, actually tabulating all exhibited case goods suit and table groups. In the past 40 years, we have evolved a chart of trends covering woods used, styles and color trends. We now can detect the start of a new direction or trend in consumer buying preferences. This information is important in establishing sales goals and promotion efforts. Furniture styles also influence the important kitchen, TV, and Hi-Fi cabinetmakers, though they usually follow these trends by 18 months to 2 years.

Since the western hardwood industry lacks a strong promotion program most of the effort should be concentrated in penetrating the midwest and east. California is already sold on alder as a product, though they still import large quantities of similar woods from Canada and the south. More

ntensive work on the midwest and eastern furniture companies who use wood roducts will automatically influence other segments of the woodworking ndustry. Concentration on the use of character marked woods will be of pecial benefit since knots and swirls are a large part of the alder pro-uction grades. Alder has more than its share of sound knots that can be eadily machined. Recent changes in style and species preferences for bed-oom and dining room suites in the southern furniture market are shown in able 1. This chart is reproduced through the courtesy of the Fine Hard-oods/American Walnut Association. Table 2 is a comparison from the large egional markets in Chicago, Dallas, and San Francisco. Occasional tables roups, which often reflect consumer buying preferences sooner than case oods, have been tabulated by the staff of the Northwest Hardwoods Inc., and re reprinted with their permission.

The potential growth of the market for western alder and big-leaf maple as not been reached and could easily be doubled in 5 years with a carefully lanned sales activity. It is truly remarkable that the volume sales has een sustained contrary to the overwhelming popularity of the strong char-cter woods such as oak, ash, pecan, and pine.

The key to further penetration into the wood markets rests with those t this conference. It involves a more positive attitude of the importance f western hardwoods to the community payrolls, backed by more consistent uality control measures. A carelessness in grading has been a blight on ur western industry for years, and recent "loose grading" has riled many ine firms who have long memories.

Selling must be in depth, involving design, finishing and production achine changes in the buyers plants. We need to cultivate a stronger dis-ribution pattern to accommodate the hobby trade, the custom plants and the uge remodeling market. We should cultivate the high school shop instruc-ors so their graduates will have more confidence in working with wood and ith our northwest hardwoods. All of these activities need promotion by ublicity and advertising to specific markets.

Table 1--*Furniture style and species changes: April 1976 to April 1977--southern furniture market survey--bedroom and dining room suites*

Item	April 1976 Number suites	April 1976 Percent	April 1977 Number suites	April 1977 Percent	Percent difference
Woods:					
Walnut	220	8.0	119	4.5	-3.5
Mahogany	52	1.9	50	1.9	0
Cherry	173	6.3	171	6.5	+.2
Maple	218	7.9	205	7.7	-.2
Oak	469	17.1	580	21.9	+4.8
Butternut	21	.8	--	--	--
Pecan	260	9.5	257	9.7	+.2
Birch	5	.2	--	--	--
Pine	286	10.4	308	11.6	+1.2
Olive-ash-burl	27	1.0	36	1.3	+.3
Ash	27	1.0	65	2.4	+1.4
Prima vera	53	1.8	44	1.7	-.1
Elm	13	.5	32	1.2	+.7
Prints & plastics	590	21.5	476	18.0	-3.5
Painted	270	9.8	216	8.1	-1.7
Other - solids[1/]	11	.4	21	.8	+.4
Other - veneers[1/]	42	1.5	65	2.5	+1.0
Glass - chrome-brass	11	.4	5	.2	-.2
Total	2,748	100	2,650	100	
Styles:					
Modern					
Contemp. Modern		25.8		29.0	
Commercial Modern		.1		0	
Total		25.9		29.0	+3.1
French					
Provincial		9.4		7.3	
Court		1.0		2.5	
Total		10.4		9.8	-.6
American		37.4		40.6	+3.2
Italian		13.7		9.0	-4.7
Spanish		7.8		5.0	-2.8
English		4.8		6.6	+1.8
Total		100		100	

[1/] Includes: avodire, acacia, bamboo, cane, mozambique, poplar, alder, ramin, teak, yew, chestnut, gum pao ferro, satinwood, rosewood, mappa burl and others not listed separately.

Source: Fine Hardwoods-American Walnut Association, 666 N. Lake Shore Dr., Chicago, Ill. 60611

Table 2--*Geographic preferences for wood tones and styles--occasional table survey at winter furniture markets*

Item	Chicago	Dallas	San Francisco
	599 table groups	790 table groups	793 table groups
	- - - - - - - - - -	-Percent-	- - - - - - - - - -
Woods:			
Oak	14.3	19.1	24.2
Pine	8.0	11.7	9.5
Maple	5.2	8.0	3.0
Walnut	8.0	2.4	6.1
Pecan-hickory	6.0	8.0	5.8
Mahogany	5.3	5.3	3.1
Cherry	5.7	5.7	2.0
Alder	.7	1.2	2.4
Birch	.7	.6	1.1
Burls	8.1	5.4	8.6
Other woods	7.9	5.4	5.1
Bamboo-cane wicker	3.0	1.5	3.4
Plastic	3.2	3.9	1.8
Printed grain	10.0	11.3	11.4
Painted	3.3	2.7	3.0
Glass-marble metal	10.6	7.8	9.5
Total	100	100	100
Styles:			
Contemporary	50.9	59.5	64.7
Ranch	4.0	4.4	4.4
Oriental	5.9	1.9	4.0
Early American and Colonial	15.5	18.0	11.1
English	13.7	8.7	7.7
French	3.8	3.7	4.8
Spanish	3.3	2.3	1.2
Italian	2.8	1.5	2.1
Total	100	100	100

Source: Northwest Hardwoods, Inc., Portland, Oreg.

THE POTENTIAL FOR INTEGRATED UTILIZATION OF ALDER

DAVID G. BRIGGS, Assistant to the Dean
College of Forest Resources
University of Washington
Seattle, Washington

JAMES S. BETHEL, Dean
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

In attempting to evaluate utilization possibilities from forest stands, we are often confronted with an array of data that is either in the wrong units of measurement or has inappropriate utilization assumptions built in. Ecologists can often provide biomass data; but this is usually expressed in terms of total weights of crowns, stems, and roots with little regard to components useful to man. The foresters' tools are log rules, volume tables, and yield tables; but these are of limited value because they often incorporate fixed and somewhat arbitrary assumptions concerning product mix and manufacturing parameters.

What is needed is a method that views the stand in terms of its basic units, the trees, and on the basis of the sizes and shapes of trees can apply relevant manufacturing requirements to obtain estimates of product output. Such an approach is described and illustrated where an alder stand is being considered for conventional sawlogs and pulp, logs SHOLO and pulp, and a mixture of the two.

Introduction

Growing concern over the proliferation of natural alder stands following turbances by logging or fire has led to increased interest in alder utiation, and consideration of whether it is more profitable to remove these er stands so they can be replaced by conifers or to examine the conditions er which alder can be maintained as a renewable materials resource. Ecoists study the productivity of forest ecosystems in terms of organic protion, but such studies typically concentrate on productivity in terms of al biomass expressed as weight per unit area, without much reference to components that are used by man. Alder has been studied in this way with relationships describing biomass per unit area and the distribution ng root, stem, and crown components. Unfortunately, this kind of informa-

tion does not readily translate into estimates of products that are used b man. In fact, many different assortments of products can be obtained from this biomass, and the mix of products obtainable is often subject to chang due to changes in utilization criteria which evolve from technological and market conditions.

Foresters have developed counterparts to the biomass studies in which attempts are made to predict the usable volume in the stand. Board-foot yield tables, volume tables, and log rules are among the devices commonly used to predict product output. Unfortunately, these rules and tables hav built in assumptions about the utilization practices and standards of indu For instance, the Scribner log rule ignores taper, and assumes 1-inch lumb thickness, and 1/4-inch sawkerf. Volume tables, in which an attempt is ma to relate some easily measured tree dimensions (diameter, height, and form to volume often compound these assumptions by attempting to estimate the volume in the tree convertible to a particular product, such as lumber or cordwood. In this case, assumptions are made about stump height, log leng minimum log diameter, minimum tree size, and the product to be made from t tree. In yield tables, stand volume per unit area is estimated according age and other stand conditions; such tables also indicate the quantity of timber that can be expected for stands under the stated conditions. Yield tables are often based on a single product assumption and build in many of the previously stated assumptions.

The basic problem confronting someone evaluating the utilization of a stand is that each of these rules and tables is essentially a model of how those who prepared them expected the industry to behave. Perhaps, they we reasonably accurate for a while; but as technology and market conditions change they become increasingly obsolete tools for estimating what can be obtained from the forest. As an example, consider the problem of using an alder volume table giving Scribner volume above a 1-foot stump according t number of 8-foot logs to an 8-inch top diameter when in fact, your alder facility segregates out 8-foot veneer logs to a 16-inch diameter limit, processes 8-foot, 10-foot, and 12-foot sawlogs to a 12-inch limit through thin kerf bandmill, and processes fiber material to a 4-inch limit. Also, how can one assess the impact of a change to processing sawlogs to a 10-in limit? It is not an easy task to accurately make such predictions on the basis of tables which are based on a set of irrelevant or antiquated technological assumptions. The need for carefully characterizing the availabl raw material in terms of a conversion facility has often been emphasized (*6*). What is needed is a more flexible approach that views the whole tree as the basic unit and the forest as a collection of such units, and then allows any set of utilization parameters to be matched to the trees. Such an analytical system would improve our ability to address many of the difficult utilization questions.

The main problem of effectively using any stand is that of matching t biomass produced by the forest system to the available manufacturing and marketing system. At one extreme is the tropical hardwood forest, which i some cases may have more than 100 different species per hectare (2.5 acres)

y of these species may be of no value to the available utilization infra-ucture. If the only conversion facility available to such a tropical nd is a sawmill, then the utilization potential of the forest will be ited to that portion of the forest biomass that can be converted to the cies, sizes, and grades of lumber that reasonably available markets will ept. In this case, the remainder of the forest is essentially worthless d material as far as a particular mill is concerned even if knowledge of to use some of the "weeds" by other processes is available.

The addition of new facilities such as veneer and pulp may increase the ble portion of the stand but may also remove some raw material from the mill. Changes in the market or development of uses for some of the weed cies further complicates an analysis of how such a forest may be used. n if the characteristics of a species permit its effective use, it may ain underutilized or may not be used at all if the cost of delivering it the ultimate consumer is too great when compared with a competitive erial.

In the Pacific Northwest, a similar situation has existed. Many years most species except Douglas-fir were weeds. Later, technologies and kets developed and hemlock and other conifers have assumed an important e in the forest economy. More recently, the hardwoods, particularly red ler, have begun the same evolutionary process. Fortunately, the weed ponent of Northwestern forests is quite low and most species have high ue. With alder, however, the present utilization system is limited. st of the alder roundwood harvest is produced as 8- and 10-foot high ality sawlogs for the manufacture of furniture lumber, or it is used for lp. The combination of these two major uses may be such that many alder ands are operationally submarginal. The problem of improving the match tween the alder stands and the conversion system may be treated in two ys.

1. If continuous use of alder on the same land is feasible, alder stands can be modified through more intensive management to produce a larger fraction of usable material per tree, per acre, and per unit of time.

2. Attempts can be made to modify the conversion and marketing system to allow for the better utilization of present natural stands.

Unfortunately, the former option requires much time while the latter quires much capital. In any specific situation, the solution chosen is kely to involve a mixture of the two options. All too frequently, dis-ssions with respect to some mix of these options is taken on the basis of adequate prior analysis and poor information. Testing the viability of ternatives through pilot commercial trials is generally too expensive. In is paper, an approach will be described that can be used to examine these estions. The approach was specifically developed to aid in answering rdwood utilization questions for tropical forests, but it is readily adapt-le to other forest settings.

A Forest Utilization Analysis System

Figure 1 portrays the overall scheme. The forest stand and utilizati criteria for the facilities are described and the models for harvesting, bucking, and primary manufacture (lumber, veneer, chips) segregate usable from unusable trees and products from residues. Along the production path numbers of pieces and cubic volumes of trees, logs, and products in green condition are tallied.

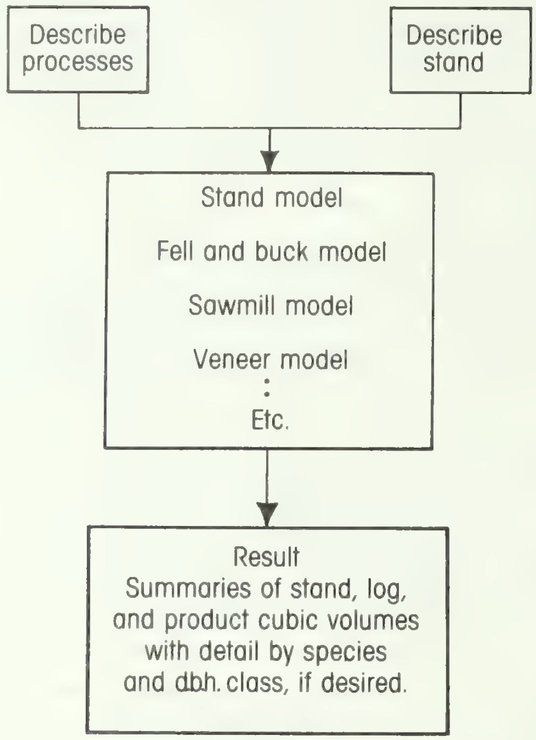

Figure 1.--Forest utilization analysis system.

This system is not unlike what one must go through in evaluating the value of a forest stand as a raw material base for a particular conversion facility. Based on some data on stand composition and structure, the volu is estimated on the basis of experience or an available volume table, and this is extrapolated to yield of products. Why, however, should a table using Scribner board feet (with 1/4-inch kerf and 1-inch lumber thickness) with 16-foot log lengths to an 8-inch top diameter be used to estimate lumber from a stand where the sawmill facility is a 1/8-inch kerf bandmill producing 8/4 stock from 8-foot and 10-foot logs to a 10-inch top diameter In this new approach, the relevant facts about the specific facility are used. The utilization assumptions of log rules and volume tables are elim inated and replaced by the specifications of a specific mix of products or facilities. In a sense, this system is like the preparation of a local

ume table except that it can rather quickly produce new tables based on v stand conditions and/or manufacturing criteria.

The stand information consists of data commonly obtained by foresters. includes age, site index, total height curves, merchantable height curves, per curves, and a stand table describing the number of trees in each d.b.h. ass. Based upon the information supplied, the dimensions and shape of a presentative tree for each d.b.h. class can be constructed and its utiliza-on potential examined. In mixed stands, some or all of this information y be repeated for each species. Presently, quality, in terms of rot, cull, d other forms of defect, is not included in the analysis. At a later time, hope to incorporate information on this aspect.

The required utilization information depends on the facility and prod-t mix to be examined. Specific modules are harvesting and bucking. They quire designation of commercial species, diameter cutting limits, stump ight, relative values of log types to be produced, desired log lengths, nimum log diameters and amount of bucking trim. On the basis of this formation, the optimum bucking pattern of each tree is determined and the rresponding output of product from each log is estimated by models of neer, sawmill, and chip processes. The veneer model requires a specifi-tion of chuck diameter and estimates the output of green veneer and resi-es from the lathe. The sawmill model is a simplified best opening face ogram for live sawing which requires definition of target lumber thickness, wkerf thickness, and minimum board width. Manufacturing residues can be located for chip or fuel production.

The system can be used to examine problems such as the following:

1. the feasibility of a particular type of stand as a raw material source for a given facility.
2. the impact of a proposed facility change or a market change resulting in a modification of utilization criteria. The feasibility of a stand as a raw material supply source can, thus, be re-examined under the new conditions.
3. the impact of complimentary or competing facilities.

With traditional tools there would not be the time, information, or the exibility to adequately examine the implications of such problems. With is approach, a small computer can perform these analyses in a relatively ort time.

To summarize and integrate the results of these analyses, a reference terial system (RMS), which is a network representation of the flow of terials from forest through the various production steps, is used. A path-y or trajectory is developed linking the resource components, processes, oducts, and residues. The quanitities of appropriate material predicted the system are displayed along the trajectory. To this physical flow, ta may be added containing information on labor, capital, process energy quirements, value added, or other pertinent information. A succession of 1S trajectories based on different utilization assumptions and stand condi-ons provides much insight when evaluating alternatives.

An Examination of Alder Utilization

To illustrate the application of the analysis to alder, an alder stan was used as a case study to test three possible facility configurations. The three configurations were a conventional sawmill producing furniture lumber, a SHOLO (short log) mill producing pallet decking lumber, and a combined complex producing both materials.

The SHOLO concept was developed in the eastern United States (*2*, *4*, *5* as a new way of profitably converting low-grade hardwood trees and logs in products. It has also been suggested as a possibility for improving utili- zation of aspen in the Rockies (*8*). With this concept, each processing st after felling is aimed at specific end products. Long, low-grade logs are bucked into short logs which contain the desired end product, plus an allowance for end trim. Conventional lumber is not produced. In this way gross defects are eliminated at the bucking station, and the effect of allowable defects is controlled by positioning the SHOLO log relative to th saw. This system can, therefore, utilize stems which are too small or too defective to produce a good conventional log but which still contain some decent material. In the example we will use the SHOLO concept for production of pallet deck lumber although the concept can also be used as a method for obtaining specific furniture parts from trees that otherwise could not be profitably processed.

The stand to be examined is based on data collected from 4.3 acres o the Pilchuck Tree Farm near Bryant, Washington.[1] These data were collecte during a research program initiated by John Hauberg about 20 years ago. At that time the stand was approximately 40 years old and 90 feet tall. This translates into a site index of 100 on a 50-year basis (*1*). The average diameter was nearly 13 inches, and trees ranged from 5 inches to 25 inches. Alder constituted 118 stems per acre, and other species (Douglas-fir, bigleaf maple, western red cedar, western hemlock, and black cottonwood) accounted for another 62 stems per acre. Alder made up about two-thirds of the stems and about three-fourths of the basal area. Total height and height to live crown relationships were developed from data fro stands in western Washington.[2] A published taper equation for alder will used in this example (*3*). Table 1 summarizes stand information and presen the utilization criteria for the conventional and SHOLO systems. It is al assumed that the logging system also produces 8-foot pulplogs from the sta Log values used are relative values, which are based on the assumption tha a cubic foot of a conventional sawlog used for furniture is worth three ti

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[1]Stenzel, G., and D. P. Thomas. 1956. Studies in management and utilization of upland red alder. Coll. For. Res., Univ. of Washington, Seattle (unpublished).

[2]The authors express appreciation to Dr. Dean DeBell of the USDA Forest Service, Forestry Sciences Laboratory, Olympia, Wash. and Mr. Boyd Wilson, Forest Land Managemen Center, Washington Department of Natural Resources, Olympia, Wash., for providing data for the development of these relationships.

s much as a cubic foot of a pulplog and 1.5 times as much as a cubic foot of a HOLO log. A cubic foot of a SHOLO log is assumed worth twice as much as a ulplog. In reviewing the results, the criteria and relative values must be ept in mind. The value of this method is that if results are desired for ifferent values or criteria, they can be quickly produced.

Table 1--*Summary of stand data and utilization criteria for conventional and SHOLO systems*

A. Stand data

Stand table

D.b.h. inches	5	6	7	8	9	10	11	12	13	14
No. trees/A	0.2	2.1	5.6	4.2	7.9	14.7	12.3	12.1	10.3	11.4

D.b.h. inches	15	16	17	18	19	20	21	22	23	24	25
No. trees/A	10.0	8.3	5.3	7.5	1.8	1.6	0.7	0.7	0.5	0.2	0.4

Total height curve

$$\text{Total height} = .1096\ (\text{stand age})^{.3345}\ (\text{site index})^{1.0628}\ (\text{DBH})^{.2186} \quad ;$$

where,

r^2 = .763, and
se = 8.3 feet = 10 percent of mean height.

Height to live crown curve

$$\text{Merchantable height} = .0020\ (\text{total height})^{1.7771}\ (\text{stand age})^{.5586} \quad ;$$

where,

r^2 = .801, and
se = 14.1 feet = 33 percent of mean merchantable height.

B. Utilization data (Stump height = 1 foot)

Log criteria

	Type	Length (feet)	Trim	Relative value/CF	Minimum diameter (inch)
Conventional	SAW	8	0.5'	3	12
	SAW	10	0.5'	3	12
	PULP	8	--	1	4
SHOLO	SHOLO	40(inch)	0.5'	2	8
	PULP	8	--	1	4

Sawing criteria

Target lumber thickness 1 3/16 inch
Minimum board width 4 inch
Kerf 1/8 inch
All slabs, edgings, and trimmings to chips
All sawdust to fuel

Results

Predictions for these three conversion alternatives are summarized in figure 2. At each point, the three numbers presented refer to (top to bottom) the conventional, SHOLO, and combined facility respectively.

The stand volume is estimated to be 4,559 cubic feet, including stump and top and excluding bark. In this example, only alder is being considered so there are no unusable or weed species comprising part of the volume. All of the alder is assumed to be felled in one operation. In some cases, with other species, cutting limits may be imposed and the usable and unusable trees would be segregated.

In the conventional system, 1,773 cubic feet of sawlogs, 1,606 cubic feet of pulplogs, and 1,180 cubic feet of forest residue (stumps and tops) are produced. The sawlogs yield 1,146 cubic feet of rough green lumber for furniture, and the sawmill produced 171 cubic feet of sawdust and 456 cubic feet of chipped slabs and edgings. If we consider both the sawmill chips and the pulplogs, about 2,062 cubic feet of material for pulping was produced from this stand.

When the stand is considered only for the SHOLO logs and pulp, 3,143 cubic feet of SHOLO logs and 241 cubic feet of pulplogs are produced. The SHOLO logs yield 1,887 cubic feet of pallet lumber, 327 cubic feet of sawdust, and 928 cubic feet of chips. The total material available for pulping is 1,169 cubic feet.

The bottom series of numbers along the trajectory indicate the results when the conventional and SHOLO systems are combined into an integrated system for processing this stand. Relatively little impact is made on the conventional lumber, but a substantial amount of volume that would otherwise be chipped for pulp can be salvaged for pallet material with the use of the SHOLO system.

This example illustrates the way in which the system can be used. Although not indicated along the trajectory, the anlaysis also provides piece counts indicating how many trees, logs, and pieces of lumber will be handled. Together, this volume and piece count information is very useful in understanding the interrelationships between products and the effects of changes in their relative values and in their processing factors. If, for instance, it was desired to determine the effect of changing the SHOLO minimum log criterion to 10 inches diameter, the analysis would be redone and a trajectory comparable to figure 2 would be developed.

The predicted stand volume of 4,559 cubic feet of alder per acre, where alder comprised 76 percent of the basal area stocking, compares favorably with the alder normal yield table (*7*) figure of 4,720 cubic feet per acre which is based on stands with at least 80 percent alder basal area.

As a final comparison, the alder predictions have been converted to a dry weight basis for comparison with published biomass data for alder stands

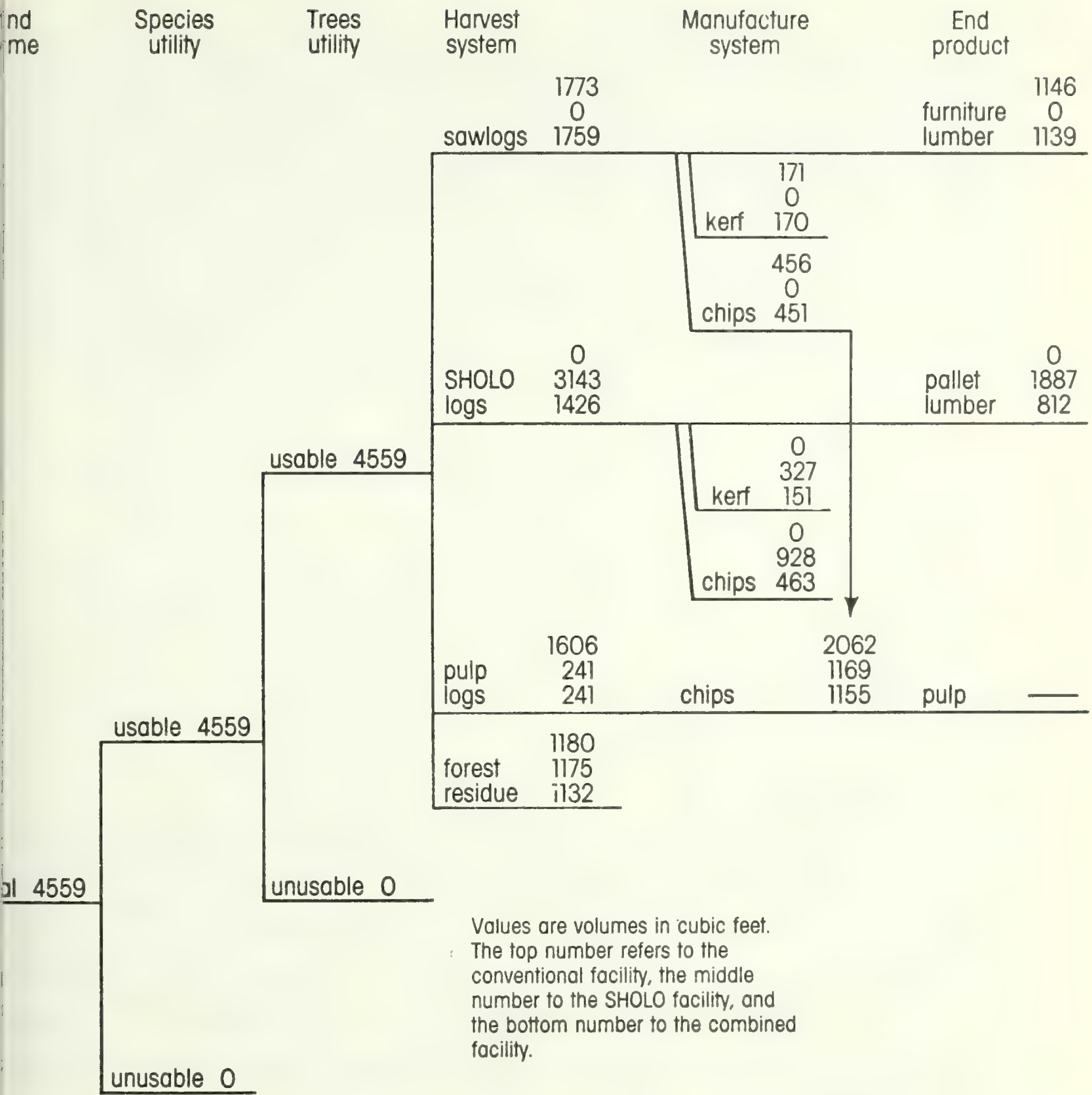

Figure 2.--RMS trajectory for three facility configurations.

(9). From the graphs in this study, the total alder biomass above ground for 40-year-old natural alder stands was estimated to be about 200 metric tons per hectare (89 short tons per acre). Roots are estimated to increase this by about 20 percent. Of the above ground biomass, if codominants are used as the typical tree, about 20 percent is estimated to be in the form of crown including foliage; bark was estimated as about 10 percent of stem weight. These estimates from the biomass study were used to develop the left bar diagram in figure 3 where weights are presented in short tons per acre. The model-predicted stem volume is in reasonable agreement with this biomass approach estimate of stem wood. The remaining three bar diagrams indicate how the three systems utilize this stand. The drop-off from stem to logs represents forest residue such as stumps and top material that is too small to use.

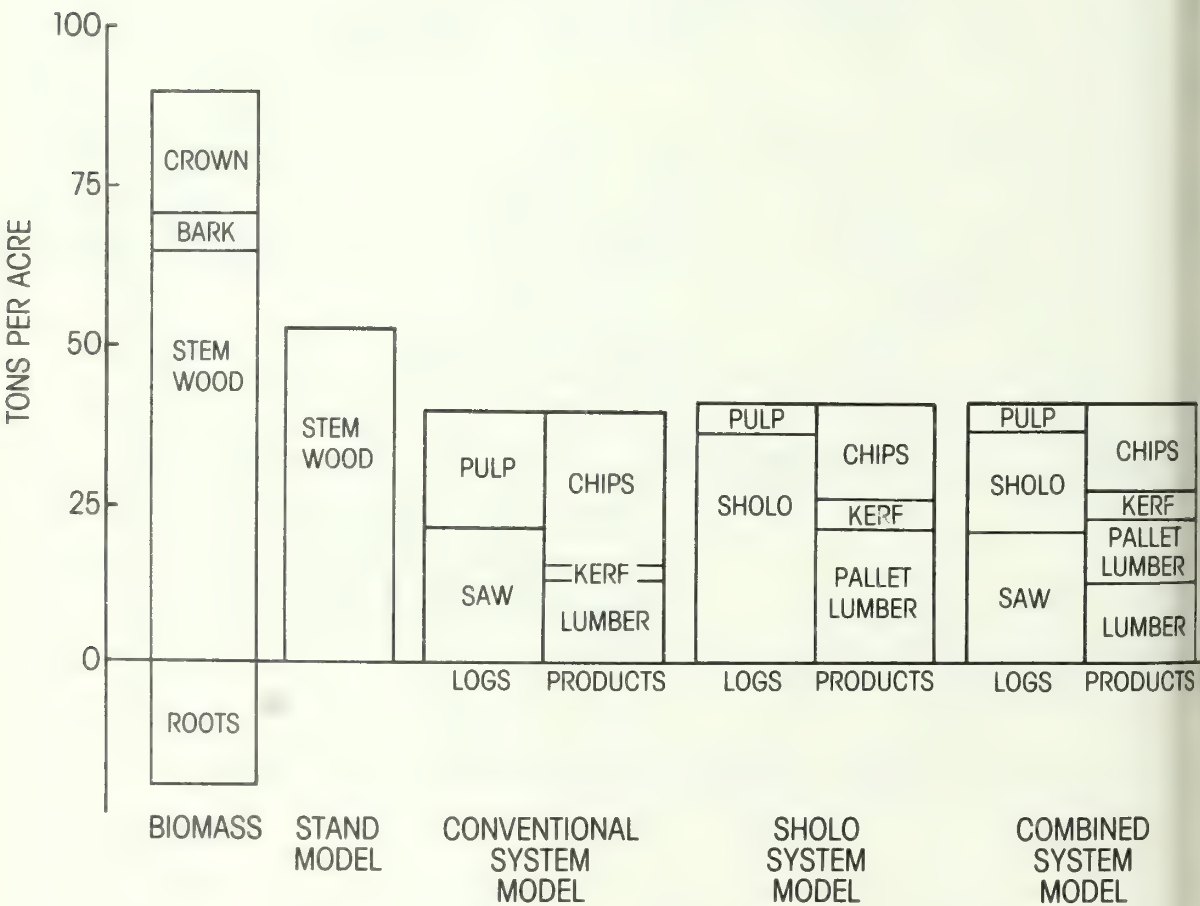

Figure 3.--Comparison of biomass with predicted utilization of a 40-year-old site index 100 alder stand.

The data suggest that the efficiency of natural alder stands is low when developing usable raw material for the primary lumber product. Conversely, one might say that the present system cannot efficiently make use of the material produced by the stand. There seems to be substantial room for improving the match between the utilization and forest production systems; working together, forest managers, researchers, and the alder industry can make improvements.

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A COMPARISON OF RED ALDER, DOUGLAS-FIR, AND WESTERN HEMLOCK PRODUCTIVITIES AS RELATED TO SITE— A PANEL DISCUSSION

GERALD HOYER
Silviculturist
Department of Natural Resources
Olympia, Washington

MICHAEL NEWTON
Professor of Forest Ecology
Department of Forest Science
Oregon State University
Corvallis, Oregon

WALTER FERGERSON
Consulting Forester
Portland, Oregon

DAVID R. M. SCOTT
Professor of Silviculture
College of Forest Resources
University of Washington
Seattle, Washington

Introduction

A general hypothesis might state that all native tree species of an ea are most productive on that particular site where the complex comnation of climatic and adaphic factors is most nearly optimal. This is t to suggest that all species are equally productive or competitive in at specific environment. Moving from this optimum site along some adient of environmental change (which by definition must be a worsening decline), it is reasonable to assume that each individual species will cline differently in terms of productivity, simply because each is ique genetically and therefore ecologically.

This hypothesis might be modelled graphically as suggested in figure 1. viously a very large number of such over-simplified gradients might be

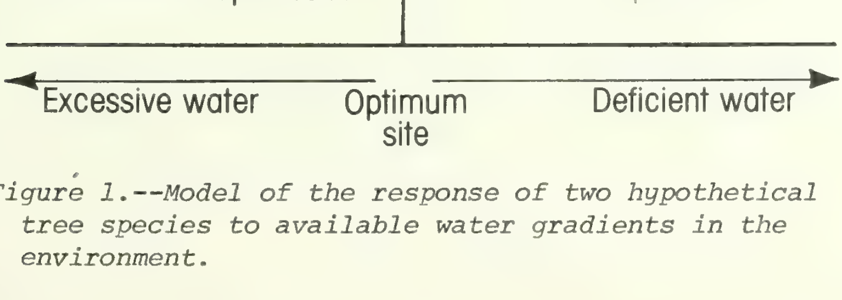

Figure 1.--Model of the response of two hypothetical tree species to available water gradients in the environment.

used, but two serve to illustrate the concept. It is also probably true that a single environmental factor cannot be altered without altering some other factor or factors and these may or may not be offsetting.

Conventional forestry wisdom in the Pacific Northwest has held that red alder behaves somewhat like species B in figure 1. Indeed there has even been some suggestion that alder was most productive, in an absolute sense, on sites that were too "wet" for best growth of conifers.

In the present discussion, the panelists examine existing evidence and introduce new data bearing on these points.

David R. M. Scott

Relative Site Index

Several comparisons of relative site index of red alder and Douglas-fir appear in the literature and are summarized in figure 2 together with previously unpublished information.

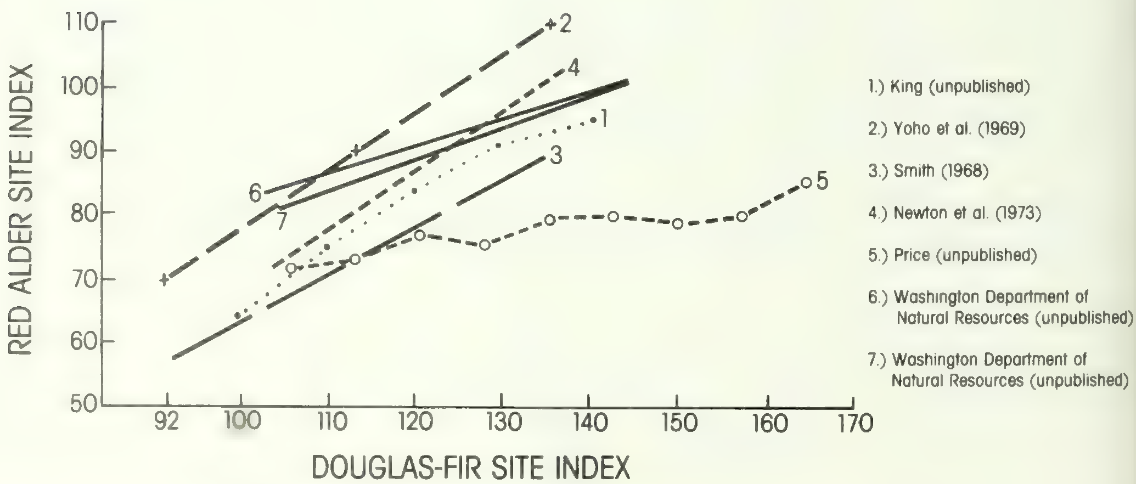

Figure 2.--Red alder and Douglas-fir site index relationships.

Relationship 2 was used by Yoho et al. (1969) for economic analysis and reported as a "consensus of expert opinion."

Relationship 3 was developed from 403 sample plots in the Powell ver area of southwestern British Columbia as reported by Smith (1968).

Relationship 4 is an adjustment of data given by Newton et al. (1973). t is based on 40 stands located from Tillamook to Oak Ridge, Oregon. wton et al. (1973) used height-age trends of McArdle et al. (1961) as e basis for the Douglas-fir indices. These have been changed to con- rm to the Douglas-fir height trends of King (1966).

The remaining relationships in figure 2 are based on previously published field data sets. Relationship 1 is from data collected in uthwestern Washington.[1] Line 5 is developed from Douglas-fir and red lder trees from 151 inventory plots on the Siuslaw National Forest.[2] ines 6 and 7 come from data collected in the Washington Department of tural Resources' red alder studies. Line 6 comprises data collected ecifically for a red alder/Douglas-fir site index comparison in which mple trees of both species were chosen close together in mixed stands d includes information from one similar plot of U.S. Forest Service igin.[3]

Relationship 7 is the compilation of site index samples taken from ther large (40 acres or more) "rehabilitation stands" in which both lder and fir were growing, mixed on a stem or small group basis. In ch of 25 stands, 20 Douglas-fir and 20 red alder trees were systemat- ally selected and measured for total height and breast height age. e sampling criteria conformed to the requirements of the red alder te index (Bishop et al. 1958) and King's (1966) site index system for uglas-fir.

The correlation of red alder site index with Douglas-fir site index s virtually the same for both 6 and 7. One line with $r^2 = .47$ for 29 mple points would be adequate to illustrate the site index correlation both sets.

The relationships shown in figure 2 are fairly consistent. All would t within the 95 percent confidence limits of relationship 7, except 5 d the lower half of 3.

Gerald Hoyer

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[1] King, James E., Weyerhaeuser Company. Personal communication. 1974.

[2] Price, F. E. Personal communication. 1965.

[3] Ruth Robert. U.S.F.S. Personal communication. 1966.

Comparing Productivity

Another method of contrasting red alder productivity with that of conifers is presented in table 1. All site indices are on a 50-year basis

Table 1--*Preliminary productivity ratings for Douglas-fir, western hemlock, and red alder (Grays Harbor, Pacific, and Wahkiakum Counties)*[1/]

Soil series	Douglas-fir (Number of plots)	Douglas-fir (Mean site index)	Western hemlock (Number of plots)	Western hemlock (Mean site index)	Red alder (Number of plots)	Red alder (Mean site index)
Group I--Well-Drained Upland Soils (400 to 1800 feet)						
Lytell	31	134	34	122	8	96
Elochoman	42	134	24	118	2	100
Zenker	19	132	16	121	8	97
Raught	8	131	5	118	2	102
Cathlamet	11	129	10	117	2	118
Germany	15	123	10	117	1	87
Wahkiakum	10	124	21	112	1	84
Squally	5	130	9	118	1	88
Bunker	8	128	27	105	1	77
Group II--Well-Drained High Elevation Soils (>1800 feet)						
Lates	3	108	16	92	1	75
Group III--Moderately Well-Drained Upland Soils (400 to 1800 feet)						
Swem	2	123	3	108	1	88
Willapa	2	125	19	115	1	68
Group IV--Well-Drained Bottomland Soils (<400 feet)						
Humptulips	0	--	0	--	1	105
Grehalem	1	137	0	--	2	104
Group V--Somewhat Poorly to Poorly Drained Bottomland (<400 feet)						
Aabab	0	--	0	--	2	89

[1/] Based on unpublished site index data and Soil Conservation Service maps on file at State of Washington Department of Natural Resources, Olympia, Washington.

Site index information for alder was developed from data collected on CFI (continuous forest inventory) plots in Grays Harbor, Wahkiakum, and Pacific Counties. Soil series determinations were obtained by "locating" these plots on soils maps prepared by the Soil Conservation Service and Department of Natural Resources. Site indices for Douglas-fir and western hemlock were based on estimates derived from preliminary soil-site relationships. All productivity information for each species was then averaged by soil series, and stratified into 5 soil groups based on elevation and soil drainage characteristics.

Certain trends became evident:

(a) Well-drained uplands are better alder producers than upland or bottomland soils with drainage restrictions. Well-drained bottomlands are also good alder sites.

(b) Among well-drained upland soils, those derived from sedimentary rocks are better alder sites than soils over igneous rocks.

(c) Site quality for alder appears to decrease as elevation increases. This may be a factor influencing the low site indices shown for the igneous soils since they were generally at higher elevations.

(d) Generally the higher the site for conifers, the higher the corresponding site index for alder.

(e) Soil maps can be a reliable base for predicting site indices provided modern soil maps are available and sufficient soil-site correlations have been made.

Walter Fergerson

Site Requirements

Site requirements of alder appear to be exacting principally at the time of establishment and after the third decade of development. Established alder grows rapidly over a wide range of sites during its first 20 years; the rate of growth during this period appears related largely to the duration of high moisture stress and moderately to temperature, with cool temperatures optimal. Growth is poor in a hot or continuously cool environment, such as a coastal environment, regardless of moisture regime.

Alder growth curves apparently do not harmonize well over a variety of sites. Height development is consistently rapid during the first 5 years in dense stands without grass cover. Heavy ground cover slows juvenile growth, especially in open-grown stands, and prevents establishment altogether when seeds are germinating.

After 5 years, favorable sites stimulate continued rapid height growth until 30 or more years of age. One 22-year-old stand has been observed with dominant trees from 88 to 92 feet tall and current increments of 2 to 2-1/2 feet per year. On poor sites, increments appear smaller in the second and later decades and, even though dominant, trees appear to be poorer competitors.

Alder growth after 40 years is difficult to study. Annual rings are often missing after age 30, and large numbers of missing rings after age 40 can compromise an effort to measure growth by stem analysis. The highest number observed was 79 rings; this was at the 60-foot level in a tree apparently 106 years old that showed 71 rings on one buttress at 4-1/2 feet.

Alder appears to require continuous dominance. There is little stratification among crown classes within a stand; mortality occurs soon after a tree drops to codominant status. Moreover, increase in the salmonberry understory after 20 to 25 years suggests that alder is unable to continue to dominate site resources.

Height growth appears necessary for crown spread, perhaps because of the ascending branching habit. For this reason, it is unlikely that diameter growth will be increased by thinning after about 15 years.

Alder is capable of providing nitrogen on nitrogen-deficient sites sufficient for its requirements, and more. Nutritional limitations are uncertain, but the need for abundant phosphorus and other macroelements is known to be prerequisite to nitrogen fixation. Cobalt, zinc, nickel, and iron are also required in nitrogen fixation; and deficiencies may account for observed nitrogen deficiencies.

The soil of alder sites should be aerated for good growth. Few sites on which alder grows well are better in the long run for hardwood than for softwood production. The peat-bog soils of the Oregon Coast Ranges that are poor conifer sites are seldom better than $SI_{50}/80$ for alder, and are usually poorer. It is likely, however, that alder is the only commerical species that can growth without root-rot problems on these sites without drainage. The presence of conifer stumps on a site indicates it is likely to grow a greater volume of softwood per acre per year than alder on rotation lengths over 25 years.

Michael Newton

Summary

What can be deduced from these presentations? Certainly there is no evidence to suggest that optimal sites for red alder are less than optimal sites for conifers. In both figure 2 and table 1, the optimal productivity of all species is found in similar environments. It should be pointed out that in figure 2 there is no direct evidence of the exact nature of the site variation. One might suggest, though, that decline in productivity is more likely to be related to excessive moisture rather than to moisture deficit because mixed stands of alder and conifers are more frequently observed on such sites. On dry sites, alder is rarely of sufficient importance to be noted mensurationally. This is borne out in table 1, where no excessively drained soils are listed and where only alder has been measured for productivity on poorly drained bottomland soils.

Further, in table 1 there is some evidence that within a general soil moisture regime class there may be more variation of alder site index than that of Douglas-fir or western hemlock. In figure 2 there is some indication of a greater relative variation of Douglas-fir than of alder.

All this suggests that alder may be somewhat less affected by excessive moisture than Douglas-fir (and perhaps hemlock) but may be somewhat more sensitive to other site factors, perhaps available nutrient levels, when moisture regime is constant. Just how such an observation relates to alder's nitrogen fixing ability is problematic.

The suggestion that estimates of alder growth or site index are often inflated due to genuinely missing rings should be regarded with some skepticism in the light of recent evidence that alder may indeed be younger than nearby conifers and that careful cross dating and ring determination techniques eliminate this factor as a source of significant error (De Bell et al. 1978).

There appear to be two circumstances where alder productivity may be superior to that of conifers. First on certain poorly drained sites where alder productivity is very low indeed but where conifers are even less productive and second on better quality sites, where management objectives, for some reason, have decreed rotations of about 20 years or less.

David R. M. Scott

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REGENERATION OF RED ALDER

REID M. KENADY, Research Associate Professor
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

*This paper brings together information regarding regeneration of red alder (*Alnus rubra *Bong.) from published and unpublished sources. Based on this evidence, red alder does not appear to be a difficult species to regenerate, either naturally or artifically. This should come as no surprise to Pacific Northwest foresters. Red alder reaches sexual maturity at around age 10 and produces large quantities of seed annually, with bumper crops about every 4 years. Natural regeneration occurs in open, disturbed areas where mineral soil is exposed. Seedlings may reach 3 feet in height the first year, and grow to 15 feet in 5 years. Alder seedlings have been successfully grown in both bare root and container nursery systems. Stratification of seed does not appear to be essential for reasonable levels of germination. Plantations of red alder have done well where reported. Coppicing of young alder is possible and offers an alternative fiber production system.*

Introduction

This paper discusses some of the phenological and silvical character-
tics that apply to establishing stands of red alder (*Alnus rubra* Bong.),
ther naturally or by artificial methods. Information has been obtained
om our own research, from the literature, and from unpublished work of
acticing silviculturists and research scientists. For making this material
ailable, the author is grateful to Dr. Dean DeBell, Pacific Northwest
rest and Range Experiment Station, USFS: Mr. Richard Reeter, Silva Seed
mpany; Mr. Frank Zelsnack, International Paper Company; Dr. George Edwards,
itish Columbia Forest Service; Mr. Dave Nelson and Mr. Robert Smith,
own Zellerbach Wood Nursery; and Mr. Bernard Bormann, graduate student,
iversity of Washington Department of Botany.

Seed Production and Dispersal

Red alder is the largest species in its genus and the dominant hardwood
the Pacific Northwest and southeast Alaska (*2*). At about age 10, indi-
dual trees begin to produce large quantities of seed, with optimum pro-
ction occurring at about age 25. Peak production years occur on an approx-

imate 4-year cycle, with light or moderate crops occurring in the intervening years. Total crop failure is a rarity, although such a failure did occur following a severe freeze in November 1955.

Red alder is monoecious, with male and female strobiles occurring on the same tree. Deviations from this norm have recently been found and are reported by Stettler in these proceedings. Male strobiles (catkins) are conspicuous in late fall preceding flowering; and female strobiles, althoug less evident, are also present at this time. Flowering may occur from late February to early May, depending on latitude and climate. Cones (female strobiles) are 1/2 to 1 inch in length and contain 50-100 small, flattened, wingless, nut-like seeds (7). Ripening occurs in the period August throug September, depending on location and climatic conditions. Seed dispersal begins shortly after conelet ripening and continues through fall and winter The seeds are light in weight (666,000 per pound) (6) and are effectively dispersed by wind. Seeds of red alder, unlike Douglas-fir, have virtually no endosperm remaining in the mature seed and food reserves are stored in the cotyledons (fig. 1).

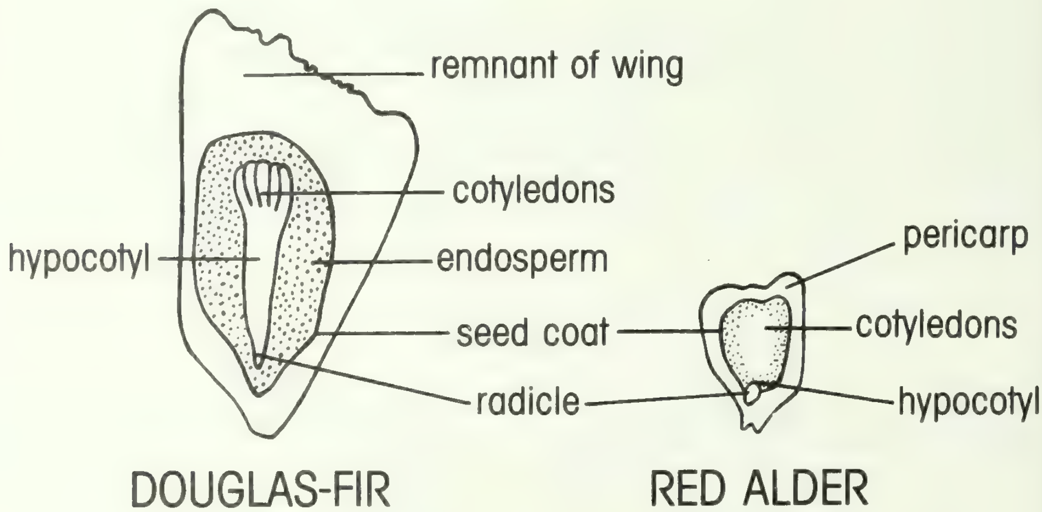

Figure 1.--Longitudinal section of Douglas-fir and red alder seed, illustrating absence of endosperm (female gametophyte) in seed of red alder (approximately 10X).

Cone Collection and Handling

Cones of red alder may be collected from standing or recently-felled trees when bracts start to separate on the earliest-developing strobiles. Collected cones may be opened by exposing to ambient air for several weeks or by kiln drying at 80°-100°F for a shorter time. In our work, we have found that cones may case-harden before collection, making it very difficult to extract seed from the cone.

Cones are considered collectable when sample cones cut longitudinally ose four filled seed per cut face. A 2-bushel sack of these cones will eld approximately 1-1/2 pounds of cleaned seed.[1] Cleaning by screening d blowing will produce above 95-percent filled seed.

Seed Stratification and Germination

Information regarding procedures for stratifying and germinating red ler seed is limited. Workers at the British Columbia Forest Service rsery at Duncan, BC, tested seed collected in 1974.[2] Following moist-d stratification, 67 percent of the seed germinated in 21 days under a gime of 8 hour 30°C light and 16 hour 20°C dark. Sixty percent of the stratified seed germinated. After 1 year's storage at -19°C, 55 percent the unstratified seed from the same seed lot germinated. Information ovided by workers from other nurseries and seed companies suggests that, the average, 50 percent of unstratified fresh red alder seed will germ-ate within 21 days.

At the University of Washington, several independent tests have been nducted on red alder seed. In one study, the effect of imbibition of ter on the germination of red alder seed was investigated. It was found at seed stored at room temperature for 3 years reached a maximum germina-on percentage after soaking in water for 24 hours. Soaking for lesser and eater periods reduced germination (fig. 2).

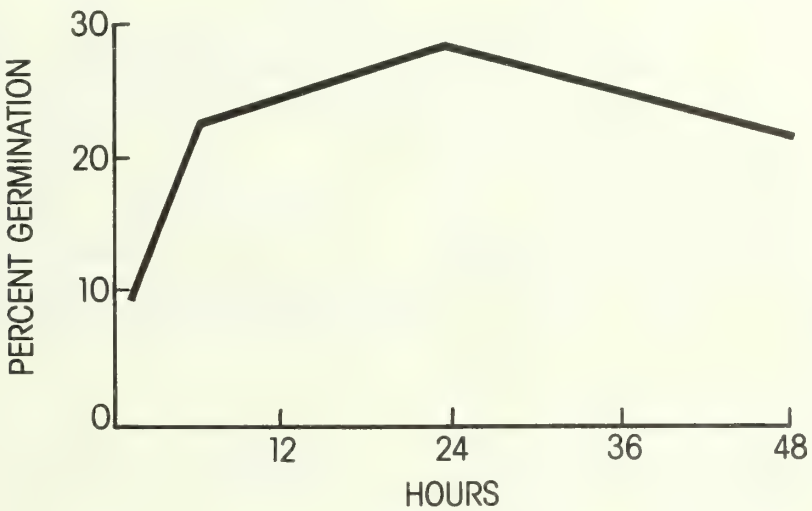

Figure 2.--The effect of soaking on the germination of red alder seed stored at room temperature for 3 years.

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[1]Patillo, G., Silva Seed Company, Roy, Wash., personal communication.

[2]Hamilton, M., British Columbia Forest Service, Duncan Nursery, Duncan, BC, rsonal communication.

In a second study,[3] the effect of light intensity on seed soaked in H_2O for 24 hours was investigated. In this experiment, light intensity was controlled but not quantified by increasing the number of Whatcom No. 1 filter papers placed over petri dishes containing seed exposed to continuou artificial light. The results of this test (fig. 3) show that germination of red alder seed decreases with decreasing amounts of light.

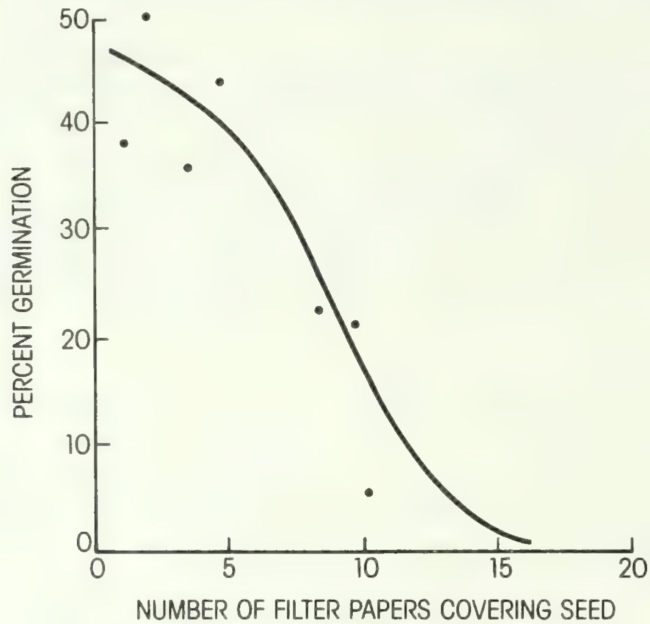

Figure 3.--The effect of light intensity on the germination of red alder seed. Intensity controlled by covering seed with filter paper.

Bormann also demonstrated that red alder seed has phytochrome-controll seed germination; that is, red light induces germination while far-red ligh strongly inhibits germination (fig. 4). Under field conditions, the impact of this mechanism would be that seeds under thick vegetative cover or deeply buried in the soil (both far-red light conditions) would not germinate until the site was disturbed so that the seeds became exposed to some daylight which is dominated by red light.

Individual trees may be expected to produce seed with different capac- ities for germination, depending upon physiological condition, nutrition, maturity, pollination, or other causes. Figure 5 shows the percentage of germinated seed taken from three trees of equal age. The seed was soaked in water for 24 hours and stored at 35°F for 6 weeks prior to germination. Although the causes of the strikingly different germination rates are not known, the data may have implications to be considered when seed collec- tions involve one or only a few parent trees.

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[3]Bormann, B. Unpublished data on file at Department of Botany, University of Washington, Seattle.

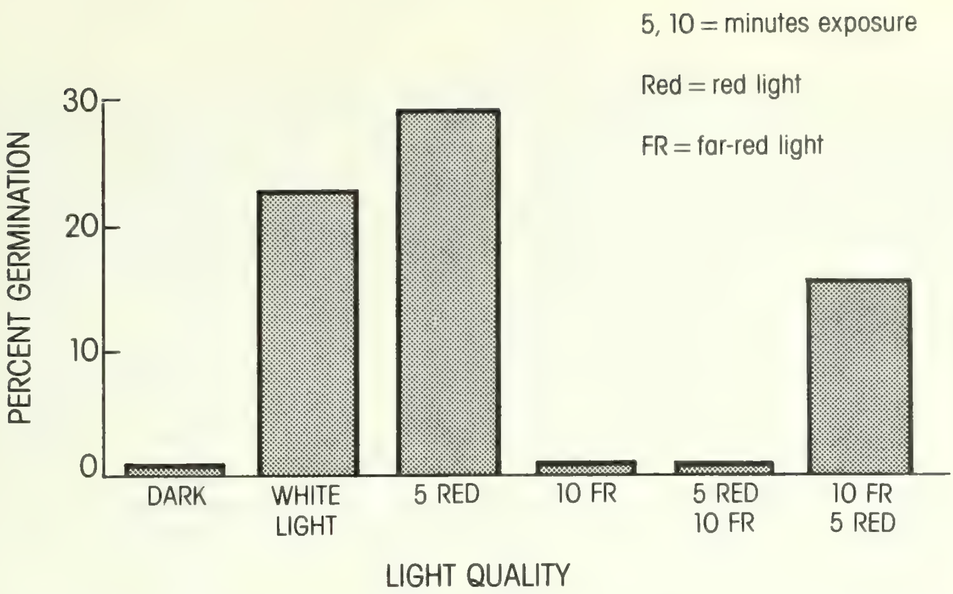

Figure 4.--The effect of light quality on the germination of imbibed red alder seeds.

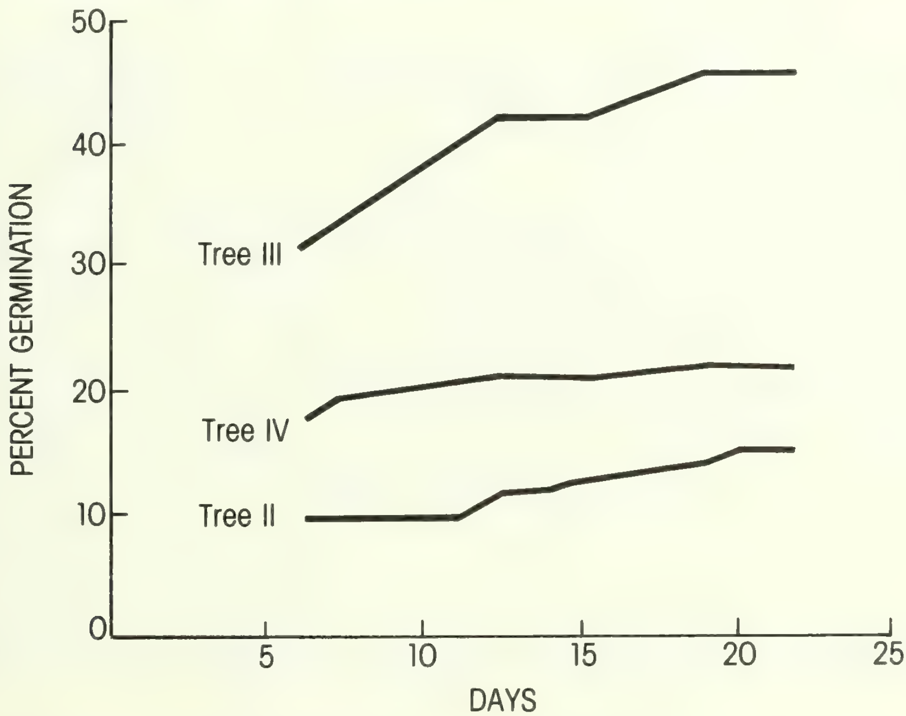

Figure 5.--Germination of red alder seed collected from three individual trees.

Under field conditions, red alder seed is commonly observed to germi-ate best on moist mineral soil exposed to full sunlight. Minore (*3*), work-ng at Cascade Head Experimental Forest, also demonstrated that red alder erminates well on rotten wood (82 percent) and duff (80 percent).

Seedling Production Systems

The procedural options for growing red alder seedlings in nursery oper- ations are perhaps narrower than for growing conifer seedlings because of the extremely rapid juvenile growth potential of red alder. Heights of 3 t 4 feet in the 1st year on good sites are not uncommon for alder. This amou of growth in nursery seedlings would undoubtedly require special handling i grown as bare root, transplant, or container stock.

Bare root red alder seedlings were grown in forest tree nurseries in the late 1940's, but operations were abandoned because of lack of interest. Recently, Crown Zellerbach and Silva Seed Company have grown red alder seed- lings in containers. At the Crown Zellerbach Ed Wood Nursery,[4] seedlings were grown in CZ-Treetainers using a peat-vermiculite-perlite (1:1:1) grow- ing media. Nutrients were withheld after mid-summer and moisture was cycled between field capacity and 5 bars stress. This regime resulted in 8- to 12 inch seedlings with good caliper and root systems after 6-7 months of growt Silva Seed Company[5] has also grown red alder seedlings in containers and advises that seed must be sown late in the spring to avoid excessive height growth. Their seedlings reached a height of 2 feet and required top prunin

Preliminary data from experiments conducted at the University of Wash- ington indicate that red alder cuttings taken in February do not readily root. Similar reports from the British Columbia Forest Service concur with these findings.[6] Schmid (*4*), working with several hardwood species, found that dormant cuttings of grey alder (*Alnus incana*) were easy to root, pro- vided that buds were retained and cuttings were treated with IBA (indole- butyric acid). Lepistö[7] reports that softwood cuttings taken from seedling during a period of vigorous growth could be successfully rooted (70 to 95 percent) when cuttings were treated with 0.5-percent IAA (indoleacetic acid in powder form and placed under intermittent mist. He further reports that scions from mature alder may be readily grafted to 1 to 2-year-old root stock using side veneer grafts near the root stock terminal.

Establishment Techniques

PLANTING

DeBell (*1*) reports average densities of 122,000 stems per acre at age 1-2 years and 14,000 stems per acre at age 8-11 years in the densest red

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[4]Smith, R., Crown Zellerbach Company, Ed Wood Nursery, Aurora, Oregon, personal communication.

[5]Reeter, R., Silva Seed Company, Roy, Wash., personal communication.

[6]Edwards, G., Canadian Forestry Service, Pacific Forest Research Centre, Victoria, BC, personal communication.

[7]Lepistö, M., The Foundation for Forest Tree Breeding, Helsinki, Finland, personal communication.

ıder stands he was able to locate in the lower Columbia River Valley. Smith) also reports similar densities working in British Columbia. With these ɪpressive numbers, the establishment of red alder does not appear to pose ıy major problem other than overstocking. Apparently, however, no one has ɪriously investigated either natural or artificial seeding of this species a silvicultural technique and there may be undiscovered obstacles in the ıy of this approach. A moist seed bed, full sunlight, and warm temperaıres are the principal requirements for germination of seed and establishınt of seedlings in natural stands. Given these conditions, red alder ɪould be one of the easiest forest tree species in the Pacific Northwest establish by either direct seeding or natural seeding when a seed source present.

Establishing stands of red alder by planting has not received much ıtention, and information is scanty. At the University of Washington Pack ɪmonstration Forest, we have had 90-percent first-year survival among wild ıder seedlings lifted after flushing and immediately transplanted to an ırbicide-treated sewage sludge area. Similar seedlings transplanted to a ın-herbicided sludge area had a 20-percent survival after one growing ıason.

Zelsnack[8] reports that container-grown red alder seedlings planted by ıternational Paper Company had a 1st-year survival of 75-80 percent. Small tyroblock-2) container-grown seedlings had a poorer survival than did ırge (Styroblock-8) container grown seedlings.

DeBell[9] planted red alder seedlings grown in CZ-Treetainers at Lady ıland. The stock had flushed at the time of planting and was damaged by ost after planting. Nevertheless, 1st-year survival was 97 percent. Bell,[10] working with the U.S. Forest Service and International Paper Company, so conducted a study in Columbia County, Oregon, in which 72-88 percent of ntainer grown red alder seedlings planted in plots of different spacings d slope positions survived the 1st year. Spacing had no apparent effect survival; however, in all cases, survival of seedlings planted at the p of the slope was greater than in plots at the bottom of the slope ig. 6). This was due, at least in part, to less competition from herbaous species on the upper-slope positions.

PPICING

Red alder may sprout from the stump or root collar after cutting and ıerefore has some potential for regeneration by the coppice method. In

[8]Zelsnack, F. Unpublished data on file at International Paper Company, ngview, Wash.

[9]DeBell, D. Unpublished data on file at Forestry Sciences Laboratory, ympia, Wash.

[10]DeBell, D. Unpublished data on file at Forestry Sciences Laboratory, ympia, Wash.

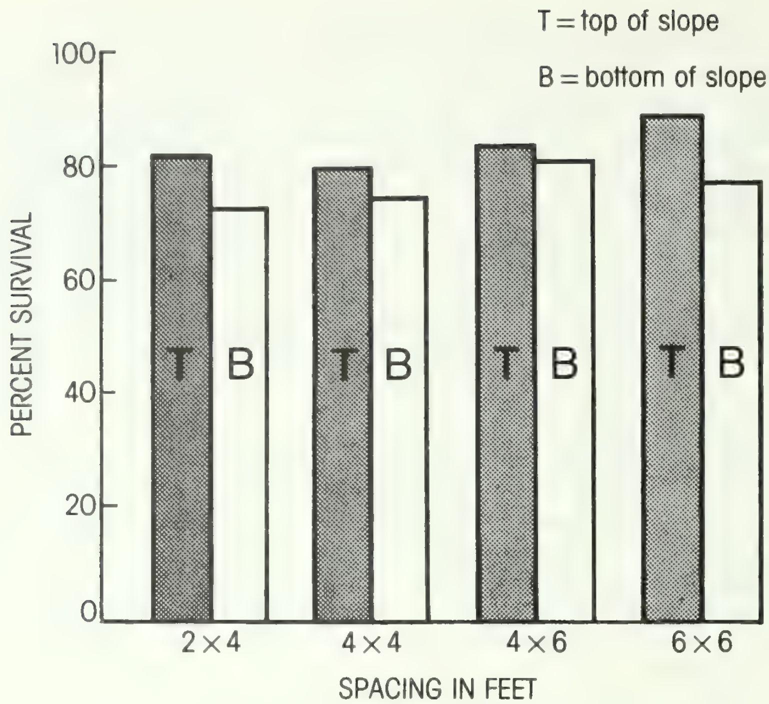

Figure 6.--Effect of spacing and slope position on survival of planted red alder seedlings.

1940, McComb,[11] working on good sites and in pure stands, cut 48 trees with breast height diameters ranging from 10 to 27 inches. The trees were cut during both dormant and growing seasons. By fall 1941, only 26 (54 percent) of the stumps had live sprouts. Of 20 stumps examined in 1945, only 1 had living sprouts and, in this case, root grafting was suspected because of the proximity of a living tree.

In April 1944, the U.S. Forest Service completed a release cutting in a dense young stand of red alder near Waldport, Oregon. At the time of cutting, stump diameters ranged from 3/4 to 6 inches at a height of approximately 4 inches. In 1947, Repraeger[12] examined 100 trees in the cut area to determine the amount of sprouting. At that time, stump diameters varied from 1 to 14 inches, with an average diameter of 4.3 inches. The 100 stumps had a total of 264 sprouts, of which 59 percent had originated from roots and 41 percent from stumps.

[11]McComb, F. Unpublished data on file at Forestry Sciences Laboratory, Olympia, Wash.

[12]Rapraeger, H. Unpublished data on file at Forestry Sciences Laboratory, Olympia, Wash.

In 1977, DeBell,[13] working at Lady Island, found that 95 percent of all, young alder (1- to 1-1/4-inch stump diameter) cut in the dormant ason had living sprouts at the end of the 2d year following cutting.

From these studies, it is apparent that young alder will develop vigor- s sprouts when cut either in the dormant season or early spring. Mature lder may sprout but much less vigorously than young alder, and the sprouts y be short-lived. Coppicing for at least one rotation may therefore be ssible in young stands.

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7) Worthington, N. P., R. H. Ruth, and E. E. Matson.
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[13]DeBell, D. Unpublished data on file at Forestry Sciences Laboratory, Olympia, Wash.

NATURAL VARIATION IN RED ALDER

DEAN S. DeBELL, Principal Silviculturist
Pacific Northwest Forest and Range Experiment Station
USDA Forest Service
Olympia, Washington

BOYD C. WILSON, Geneticist
Division of Forest Land Management
Washington State Department of Natural Resources
Olympia, Washington

ABSTRACT

An 8-year-old provenance trial examined racial variation among 10 sources of red alder from Alaska, British Columbia, Washington, Oregon, and Idaho. The fastest growing sources are from northwestern Washington, but sources from British Columbia, southwestern Washington, and Oregon also grew well. The slowest growers were from Juneau, Alaska, and Sandpoint, Idaho--they also have the greatest frost resistance.

A study of phenotypic variation between and within eight stands was conducted in a small area west of Olympia, Washington. Although the stands were selected to cover the range in site conditions occurring in the area, only crown width index, branching characteristics, and bark thickness showed significant variation between stands. Variation from tree to tree within stands, however, was substantial for all traits.

The results of these studies suggest that individual tree selection will be a useful approach in alder improvement programs and that such programs can encompass rather large areas (or breeding zones).

Introduction

Information on natural variation in growth traits and wood quality is mportant for developing efficient tree improvement programs for forest pecies. Estimates of the genetic component of existing variation or eritabilities of selected traits are also needed. Such information is imited for red alder (*Alnus rubra* Bong.) because most forest managers and cientists have shown far more interest in killing the species than in

improving it. Nevertheless, two studies provide some data on racial, stand and tree variation in red alder. One study is an 8-year-old provenance trial testing outplanting performance of seedling from a wide range of sources. The other study examines tree variability within and between stands in a relatively small portion of the species' range.

Geographic or Racial Variation

The natural range of red alder extends from southern California (latitude 34° N.) northward along the Pacific coast to Yakutat Bay, Alaska (latitude 60° N.). Though some stands have been found in northern Idaho, the species usually occurs within 100 miles of the Pacific Ocean and at elevations of less than 2,500 feet (Worthington et al. 1962). Some foresters have suggested that red alder attains its best development in northern Washington and southern British Columbia, but little or no data have been advanced to document those observations or to determine whether genetic or environmental factors are responsible.

In the fall of 1968, B. S. Douglass and R. K. Peter established a red alder provenance test with outplantings at the Cascade Head Experimental Forest near Lincoln City, Oregon, and in the Capitol Forest near Olympia, Washington. Severe frost damage in 1969 and 1970 decimated the Capitol Forest plantation. The Cascade Head plantation, however, is now growing vigorously and is in its ninth growing season. It has been evaluated six times and provides the basis for the following discussion of racial variation.[1]

DESCRIPTION OF THE PROVENANCE TRIAL

Sources of planting stock.--Natural seedlings, 12 to 30 inches in height, were collected from 10 locations during the winter of 1968-69, shipped to the Webster Nursery, Olympia, and stored at 35°F until they were sorted and planted. The locations are identified in figure 1; they include Juneau, Alaska, and Sandpoint, Idaho, in addition to eight well-spaced locations in Oregon, Washington, and the southern end of Vancouver Island, British Columbia. Latitude, elevation, and mean annual precipitation and temperature of the locations are listed in table 1.

Because all seedlings of some provenances were obtained from a very small area (e.g., less than 1 acre), they may represent a small portion of the gene pool at that general location. Moreover, the natural seedlings had already undergone some degree of natural selection and therefore are not a random sample of the gene pool at even a small locality. Thus, procedures used to sample the local populations would tend to reduce

[1]Unpublished plans, field data, and reports prepared from 1968 through 1976 by B. S. Douglass, R. K. Peter, and V. W. Clapp, USDA Forest Service, State and Private Forestry, Portland, Oregon.

Figure 1.--Locations of sources tested in red alder provenance trial.

Table 1--*Location and features of native environment for red alder provenances tested at Cascade Head Experimental Forest in Oregon*

Location	Latitude	Elevation[1/]	Precipitation[2/]	Temperature[2/]
	°N	Feet	Inches	°F
Juneau, Alaska	57.0	150	90	43
Jordan River, British Columbia	48.5	300	74	48
Concrete, Washington	48.5	300	80	52
Sandpoint, Idaho	48.4	2,300	30	45
Sequim, Washington	48.1	200	15	49
Olympia, Washington	47.0	250	50	51
Amboy, Washington	45.9	500	70	51
Lincoln City, Oregon	45.0	300	90	51
Cottage Grove, Oregon	43.8	800	50	52
Port Orford, Oregon	42.7	900	70	53

1/ Above sea level.

2/ Estimated mean annual.

variability within a provenance and thereby exaggerate differences betwee provenances. These points should be considered when the data are evaluat

The outplanting areas.--Ten acres, located at the head of a small cr on the Cascade Head Experimental Forest, were selected for one outplantin site. This area, near the town of Otis, is typical of alder sites in coastal Oregon. Elevation is 600 feet, precipitation (primarily rain) averages about 90 inches per year, and mean annual temperature is approxi- mately 52°F. Soils are derived from sedimentary materials. Originally, the area supported a mature stand of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.), averaging nearly 100,000 board feet per acre. After logging, a central 1 by 400-foot area was cleared of all debris (except large stumps) to permi uniform spacing of the alder seedlings.

The Capitol Forest site was located on a portion of an abandoned Sta nursery about 15 miles southwest of Olympia. Elevation is 600 feet; estimated mean annual precipitation and temperature are 55 inches and 51° This area was thoroughly cultivated prior to planting.

Planting design and procedures.--The experimental design consisted o eight blocks (100- by 50-foot) in two strips perpendicular to the contour. Ten rows were located at 10-foot intervals in each block. Individual rows were randomly selected for planting with 10 trees of the same provenance, spaced 5 feet apart.

The trees were planted in March and April 1969. Prior to planting, roots of all seedlings were pruned to 8 inches in length; tops exceeding 24 inches were pruned to 18 inches.

Evaluation and measurement.--Early performance of seedlings was valuated at both locations in July 1970, after nearly two growing seasons. ata were collected on survival, height, and general form. Multiple leaders nd large suckers were removed because they probably resulted from top runing and transplanting shock; thereafter, trees at the Cascade Head site veloped naturally. Unfortunately, severe early frosts damaged the Capitol orest planting in fall 1969 and fall 1970. After information on survival nd frost damage were collected in 1971, this plantation was abandoned.

Evaluations were made at Cascade Head after the 1971, 1972, 1973, 1974, nd 1976 growing seasons. Diameter measurements were initiated in 1976, 8 ears after planting. In December 1976, the test area was thinned to 10- 10-foot spacing, by removing every other tree in each row. Breast-high ood samples were collected from the cut trees for determination of specific ravity and bark thickness.

ROVENANCE PERFORMANCE

Survival.--Information on survival of planting stock is given in table 2. t Capitol Forest, the coastal Oregon sources (Lincoln City and Port Orford) nd the Jordon River stock from southern Vancouver Island were hardest hit by he fall 1969 freeze. Seedlings from Juneau, Alaska, and Sandpoint, Idaho, owever, were little affected. This is evident both in the initial survival ercentages and in the number of seedlings frozen back to ground line. Many eedlings that resprouted after the 1969 freeze subsequently died; other eedlings were killed by the 1970 freeze. By fall 1971, losses were so great hat subsequent evaluations of growth at this site would have minimal value.

Table 2--*Survival of red alder provenances at Capitol Forest and Cascade Head Experimental Forest outplanting sites*

Provenance	Capitol Forest: Initial survival	Capitol Forest: Seedlings frozen back to ground	Cascade Head: Initial survival	Cascade Head: Subsequent survival[1/]
	- - - -	- - - - Percent	- - - -	- - - -
Juneau, Alaska	95	0	94	97
Jordan River, British Columbia	41	90	94	100
Concrete, Washington	80	70	84	99
Sandpoint, Idaho	90	10	79	97
Sequim, Washington	86	65	99	99
Olympia, Washington	93	60	95	97
Amboy, Washington	89	60	96	98
Lincoln City, Oregon	63	85	96	99
Cottage Grove, Oregon	79	75	91	98
Port Orford, Oregon	39	95	89	100

[1/] These values include surviving seedlings of both initial and followup plantings.

Survival after the first growing season at Cascade Head varied by provenance from 79 to 99 percent. Replacement plantings were made from holding beds if additional seedlings from the provenances were available. Subsequent survival of seedlings (living originals plus replacements) exceeded 97 percent. Therefore, initial survival differences were probabl related to differences in handling and storage of the seedlings before outplanting rather than to genetic differences in adaptability to the Cascade Head site.

Height growth.--Average heights for trees at 2, 4, 6, and 8 years aft planting are listed by provenance in table 3. Large differences in height were evident in the 2d year. Trees from provenances with the tallest tree (Concrete and Sequim) averaged 5.0 feet in height, whereas those from provenances with the shortest trees (Juneau and Port Orford) averaged only 3.1 feet, a difference of about 60 percent. In general, such differences have persisted through the eighth growing season (table 3 and fig. 2). Trees of the Concrete and Sequim provenances now average 30.3 and 29.4 feet, whereas trees from Juneau are only 14.4 feet in height. Because of inclusion of some Sitka alder (*Alnus sinuata* (Reg.) Rydb. seedlings (about one-fourth of the Juneau stock) that were not positively identified until September 1974, the poor performance of the Juneau stock in height growth as well as other traits is slightly exaggerated. After a slow start, the Port Orford source has recovered and is now ranked fourth tallest at 27.6 feet. Nevertheless, the difference in height between tallest and shortest sources has widened to more than 100 percent.

Table 3--*Average heights of red alder provenances after outplanting at Cascade Head*

Provenance[1/]	Years after outplanting			
	2	4	6	8[2/]
	- - - - - - - - - -Feet- - - - - - - - - -			
Concrete, Washington	5.0	15.2	21.5	30.3 a
Sequim, Washington	5.0	15.3	21.7	29.4 ab
Olympia, Washington	4.8	13.8	19.6	27.7 ab
Port Orford, Oregon	3.1	11.8	18.5	27.6 ab
Amboy, Washington	4.7	13.1	19.0	27.3 ab
Jordan River, British Columbia	4.5	14.0	19.9	26.7 ab
Lincoln City, Oregon	3.6	12.1	17.5	26.4 ab
Cottage Grove, Oregon	3.5	12.4	18.1	26.1 b
Sandpoint, Idaho	3.6	10.5	15.3	21.0 c
Juneau, Alaska	3.1	7.6	10.8	14.4 d

[1/] Ranked by height of red alder at age 8.

[2/] Means followed by the same letter are not statistically different at the 5-percent level of confidence as determined by Tukey's test (Steel and Torrie 1960).

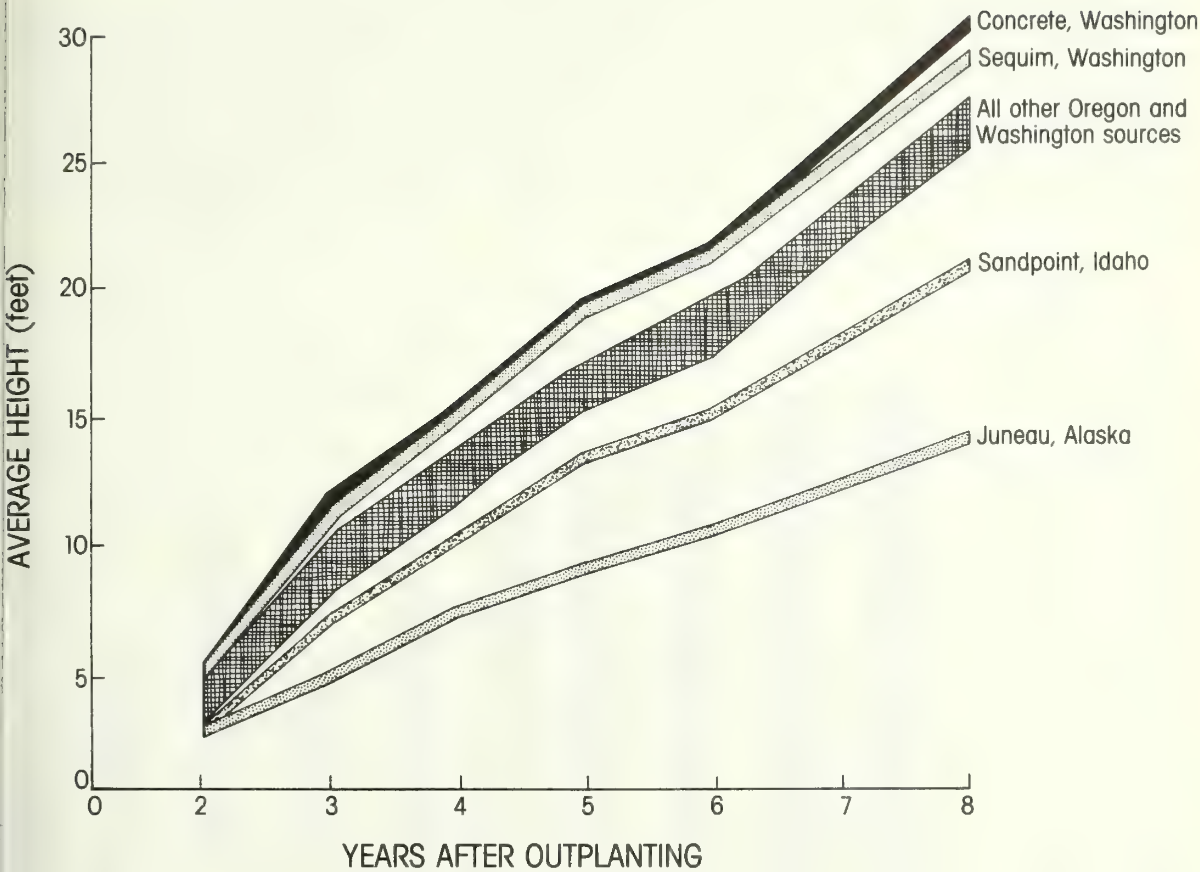

Figure 2.--Height growth patterns of red alder provenances at Cascade Head.

Based on 8-year height growth of red alder, the provenances can be split into two main groups: (1) the eight sources from Oregon, Washington and southern British Columbia which are all growing well and are led by th Concrete and Sequim stock, and (2) the two outlying sources from Juneau an Sandpoint which are growing much more slowly.

Diameter growth.--Diameters measured after 8 years indicated provenan differences (fig. 3) similar to those discussed for height growth. The largest diameters (3.6 inches) were attained by trees from Concrete and Sequim, whereas Sandpoint and Juneau sources averaged only 2.1 and 1.5 inches. Diameters of some of the remaining sources, however, were not significantly less than those of the Concrete and Sequim trees.

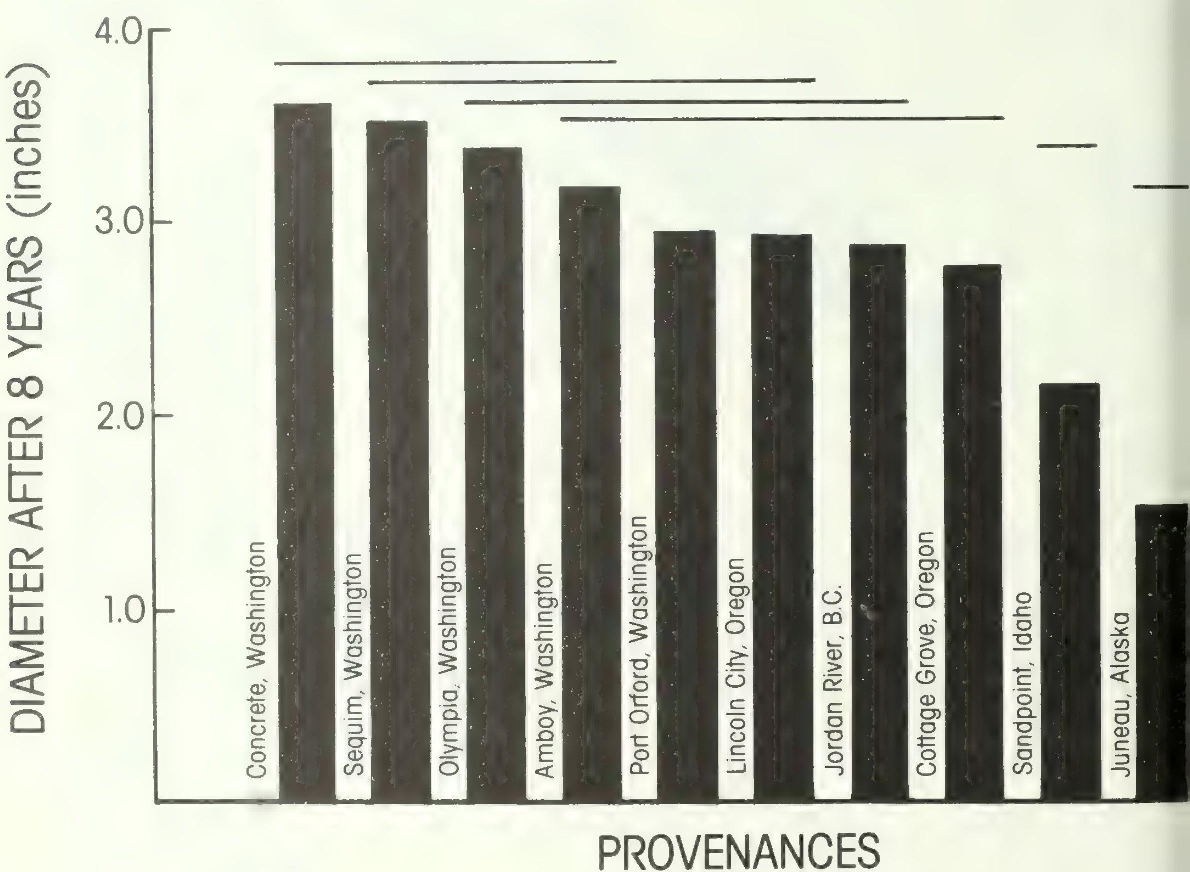

Figure 3.--Breast-high diameter of red alder provenances 8 years after outplanting at Cascade Head. Means joined by the same lines are not statistically significant.

Other traits.--Because factors other than growth rate may also be important in tree improvement programs, additional characteristics have been assessed at various times in the trial. Data on general stem form, frequency of multiple leaders, damage by a flat-headed twig girdler (*Agril* *burkei* Fisher), specific gravity, and bark thickness are given for each provenance in table 4.

Table 4--*Stem form and other characteristics of red alder provenances at Cascade Head*

Provenance[1/]	General stem form[2/]	Trees with Multiple leaders	Trees damaged by twig girdler	Breast-high Specific gravity	Breast-high Bark thickness[3/]
	- - - - - Percent		- - - - -	g/cm^3	Inches
Concrete, Washington	4.1	8	25	0.40	0.13 a
Sequim, Washington	4.6	14	30	.39	.15 ab
Olympia, Washington	4.0	13	10	.40	.14 ab
Port Orford, Oregon	2.8	28	10	.40	.14 ab
Amboy, Washington	3.5	23	19	.40	.16 ab
Jordan River, British Columbia	4.4	13	20	.41	.17 b
Lincoln City, Oregon	2.9	20	10	.39	.14 ab
Cottage Grove, Oregon	2.8	38	6	.40	.15 ab
Sandpoint, Idaho	2.3	39	10	.40	.17 b
Juneau, Alaska	1.3	50	2	.41	.14 ab

[1/] Ranked by height of red alder at age 8.

[2/] 5 = best; 1 = poorest.

[3/] Adjusted by covariance analysis to common d.b.h. Means followed by the same letter are not statistically different at the 5-percent level of confidence as determined by Tukey's test (Steel and Torrie 1960).

The sources having the best form (e.g., straight stems and small limbs), a well as the lowest frequency of multiple leaders, were Sequim, Jordon Rver, Concrete, and Olympia. These provenances are also among those having te most rapid height and diameter growth.

The fastest growing sources were hit hardest by the twig girdler in a 171 attack. Whether this damage incidence was due to genetic differences pr se or to the greater amounts of succulent tissue associated with rapid gowth is unknown. Fortunately, no twig girdler attacks occurred in sbsequent years, and by the end of the 1974 growing season, the trees had esentially overcome the detrimental effects by overgrowing and strengtheing the girdled portion or by forming a new leader below a girdler-caused beak.

Compared with previously discussed traits, racial variation in wood dnsity was minimal and differences were not significant. There was, hwever, considerable variation in wood density within each provenance. As mght be surmised from the provenance averages in table 4, wood density was nt related to growth rate. Racial differences in bark thickness were sgnificant at the 10-percent level. Because differences were also related t tree size, values were adjusted by covariance analysis to a common beast-high diameter o.b. (outside bark). Following such adjustment, racial dfferences in bark thickness remained significant.

Results from the study of racial variation are quite encouraging for alder improvement programs. Such implications will be discussed after we consider natural variation within a local area.

Phenotypic Variation Within a Local Area

Although the racial variation described previously has provided much useful information for alder improvement programs, foresters will also ne data on the magnitude and patterns of variation in certain traits within local area or breeding zone. It is within such an area that phenotypic selections can be made for the initial phases of breeding programs. Moreover, seedlings produced from seed collected in a local area can be plant with greater confidence in their adaptation to local sites. For these reasons, we initiated a study of natural variation of alder in an area we of Olympia.

DESCRIPTION OF LOCAL VARIATION STUDY

Boundaries of the local area are shown in figure 4. The Capitol For comprises most of the southern half of the unit, whereas the northern hal includes land owned primarily by forest industry.

Eight stands were selected to cover the range in elevation, topograp soils, and rainfall occurring in the designated area (table 5). Average age of the stands varied from 20 to 73 years, and estimated site index ranged from 67 to 101 feet on a 50-year basis. Average breast-high diame varied from 9.3 to 12.8 inches.

Table 5--*General characteristics of red alder stands sampled in local area near Olympia, Washing*

Stand location	Elevation above sea level	Soil parent material	Estimated annual precipitation	Stand characteristics[1]			
				Age	Average d.b.h.	Height	Estimat site ind (50-year
	Feet		Inches	Years	Inches	- - -Feet- - -	
McKenny	300	alluvium-till	45	44	11.1	87	92
Porter	550	siltstone	55	35	11.1	87	101
Rock Candy	900	basalt	55	45	11.6	82	86
Wedekind	1800	alluvium-basalt	55	20	9.3	54	87
McCleary	300	mixed alluvium	60	73	12.0	87	76
Taylor Towne	400	till and local basalt	65	56	12.8	91	87
Schafer Park	325	mixed basalt and sediments	75	54	11.9	96	93
Stillwater	250	till and local basalt	80	59	10.7	72	67

[1] Based on data collected from sample trees.

[2] Based on: Norman P. Worthington, Floyd A. Johnson, George R. Staebler, and William J. Lloyd Normal yield tables for red alder. USDA Forest Service, Pacific Northwest Forest and Range Experim Station Research Paper 36, 29 p. Portland, Oregon.

Figure 4.--Locations of stands sampled in study of phenotypic variation with local area.

Ten trees were chosen at random within each stand for assessing natural variation. After the general form of each tree was sketched and its lean and crown spread measured, the trees were felled to obtain measurements of height, upper-stem diameters, and branching characteristics. Seeds were collected for subsequent progeny trials. Also, stem cross-sections were cut at the stump for determining age and at breast height for measuring specific gravity and bark thickness.

Differences between stand means for most traits were tested by analysis of variance using a completely randomized design. Two observations of specific gravity and bark thickness were obtained for each tree, which permitted testing of the significance of differences between trees within a stand.

PHENOTYPIC VARIATION BETWEEN AND WITHIN STANDS

Trait evaluations for randomly selected trees in the eight stands are summarized in table 6. The mean, range in stand means, and range in individual tree values are listed for each trait. In addition, results of an analysis of variance of differences between stands and two expressions (standard deviation and coefficient of variation) of tree-to-tree variability within stands are given. The standard deviation is indicative of the dispersion of individuals around the mean. Expressed as a percentage of the stand mean (i.e., coefficient of variation), it is a measure of the relative variability of a given trait in different stands.

Table 6--*Summary of phenotypic variation between and within stands of a local area*

Trait	Unit of measure	Mean	Range in: Stand means	Range in: Individual tree values	Confidence level for differences between stands[1]	Range in within stand variation: Standard deviation	Range in within stand variation: Coefficient of variation
							Percent
Lean	Degrees	10	6 - 13	0 - 36	Nonsignificant	3 - 10	35 to 88
Stem form index	Percent	85	84 - 87	73 - 98	Nonsignificant	2 - 6	2 to 7
Crown width index	Feet÷inches	1.5	1.3 - 1.7	1.0 - 2.7	10 percent	.2 - .5	14 to 36
Clear bole index	Percent	54	22 - 63	11 - 82	Nonsignificant	7 - 15	12 to 32
Branch angle	Degrees	40	34 - 44	21 - 62	10 percent	6 - 12	15 to 27
Branch diameter index	Percent	38	28 - 47	13 - 74	1 percent	5 - 13	18 to 33
Wood density	Grams per cubic centimeter	.39	.38 - .40	.30 - .43	Nonsignificant	.01 - .02	3 to 5
Bark thickness[2]	Inches	.13	.09 - .17	.12 - .49	1 percent	.03 - .07	15 to 21

[1] All statements regarding significance of differences between stand means for specific traits are based on results of Tukey's test at the 5-percent level of confidence (Steel and Torrie 1960).

[2] Values for the mean and range in stand means are adjusted by covarience analysis to a common tree size (radius outside bark). Other values have not been adjusted for differences in tree size.

Only crown width, branching characteristics, and bark thickness varied ignificantly between stands. Variation among trees within stands was ubstantial, however. The traits are discussed individually in the following aragraphs.

Lean.--Lean is thought to be an important trait because leaning trees end to develop sweep which presents difficulties in handling and milling ogs. Lean is probably also associated with reaction wood which further educes lumber recovery. Magnitude of lean was measured by the angle of eparture from vertical for a 6-foot stem section centered at breast height. tand averages ranged from 6° to 13° but were not significantly different. he lean of individual random trees varied from 0° to 36° and averaged 10°. he fact that lean was somewhat related to crown width:d.b.h. ratio r = 0.27, $p < 0.05$) gives credence to the hypothesis that lean might be inimized by growing alder in well-stocked, uniformly spaced stands.

Stem form index.--Stem form index was calculated as the ratio (percent) f diameter (o.b.) at one-fourth height to diameter at breast height (o.b.). ifferences between stand means were minimal, but individual tree values anged from 73 to 98.

Crown width index.--Among trees of comparable sizes, narrow crowns may ndicate efficient use of growing space. A crown width index was therefore omputed by dividing crown width (feet) by diameter (inches). Stand means or this trait varied from 1.3 to 1.7 and differed significantly at the 0-percent level. Trees at McCleary differed from those at Stillwater with verage indices of 1.7 and 1.3, respectively.[2] Other stands did not vary ignificantly from each other in this trait. The range in values from andomly chosen trees was 1.0 to 2.7.

Clear bole index.--Height to lowest live branch expressed as a percent- ge of total tree height can be taken as an index of clear bole length and f natural pruning under existing stand conditions. With the exception of he much younger, 20-year-old stand at Wedekind (22 percent), stand means or clear bole index varied little (53 to 63 percent). Substantial ree-to-tree variation existed within stands, however.

Branching characteristics.--Mean branch angle was determined by easuring the angle with a protractor and averaging the angles of three ranches immediately above and immediately below the midpoint of the crown. ifferences between some stands were significant at the 10-percent level. rees at McKenny averaged 34°, whereas those at Wedekind and McCleary veraged 44°. Substantial tree-to-tree variation within stands also xisted--mean angles ranged from 21° to 62°.

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[2] All statements in text regarding significance of differences between stand means for specific traits are based on results of Tukey's test at the 5-percent level of confidence (Steel and Torrie 1960).

A branch diameter index was determined by averaging diameters of the six branches and expressing the average as a percent of midcrown stem diameter. Stand differences were significant at the 1-percent level. The mean branch index for Wedekind (34) was significantly less than those for the Schafer Park (41), Rock Candy (43), and Stillwater (47) sites. McKenna and Taylor Towne, with average indices of 34, also differed significantly from Stillwater. Individual tree values on all sites ranged from 13 to 74. Thus, there appears to be a rather large amount of natural variation in branching patterns of alder.

Wood density.--Wood density was determined by measuring green volume and ovendry weight of rectangular samples (three-fourths inch wide by one-half inch thick) of wood produced during the first 25 years. The samples were opposite ends of a rectangular cross section cut from a breast-high disc. Although the minimal differences between stands in mean wood density were not significant, tree-to-tree variation within stands was highly significant. Wood density of individual trees ranged from 0.30 to 0.43 g/cm^3. Fortunately, the correlation between wood density and growth rate was not strongly negative ($r = -0.120$, $p < 0.10$).

Bark thickness.--Single bark thickness was measured at opposite ends of a rectangular cross-section cut from a breast-high disc sample. Differences in bark thickness between stands were highly significant ($p < 0.01$) after adjusting for tree size (radius outside bark) by covariance analysis. The variation in bark thickness among trees within a stand, however, was greater yet. At several locations, the bark of some trees was twice as thick as that of others. The economic implications of this trait may be two-edged: (1) thick bark may be advantageous if bark is used as an energy source at mills, or (2) pulp production could be limited by recovery furnace capacity if barky chips were used as the fiber source.

Implications

Substantial natural variation in red alder has been verified in the provenance trial and in an assessment of stand and tree characteristics within a local area. Such variation exists at several levels--geographic, stand, and from tree to tree within stands. The large amount of variation in economically important traits between individual trees within a stand is a good omen for selection approaches to genetic improvement of red alder.

Excellent performance of most provenances of red alder at Cascade Head suggests that it may be possible to move reproductive material to mild sites over rather long distances along the coast. Such inferences, however, drawn from a planting trial at one location, must be made with caution; and the frost damage sustained at Capitol Forest (an inland site) is indicative of problems that can arise. The Capitol Forest experience parallels an earlier report on frost damage to alder stock collected from an Olympia seed source at 50 feet above sea level and planted at an

evation of 2,500 feet on the Wind River Experimental Forest near Carson, shington (Tarrant 1961). Except for the poor performance of the Juneau d Sandpoint provenances (the geographic extremes of the species' range), asons for relative performance of various sources at Cascade Head are not vious. That two of the best sources, Concrete and Sequim, originated in eas of diverse rainfall (80 and 15 inches, respectively) illustrates this ck of obvious explanations. Although rapid growth is desirable for wood oduction, the slow-growing Sandpoint and Juneau sources may be useful for terplanting with Douglas-fir and other conifers. Their slow growth would t pose severe competition to conifers, and yet some soil-improving benefits .g., nitrogen accretion as determined by Tarrant and Miller (1963)) could provided.

Fortunately, some desirable traits (e.g., rapid growth rate and stem rm) appear to be expressed early and positively associated with each her. Although attack by twig girdlers was related to rapid growth, the maging effects were overcome by the fast-growing trees. Moreover, lack of strong negative correlation between wood density and growth in both udies suggests that foresters can select red alder trees for rapid growth thout unduly sacrificing wood density and vice versa.

Of eight variables measured on 10 trees in each of eight stands in a cal area of western Washington, only crown width index, branching traits, d bark thickness were significantly different between stands. This lack significant variation between stands in most traits suggests that zones least this large could be used in breeding programs. Moreover, this nding and other observations suggest that variation among trees within ands is far greater than variation between stands. Therefore, individual ee selection should be a useful tool in an alder genetics program.

Available information on magnitude and patterns of natural variation s most encouraging for red alder improvement programs. Though the portion f this variation in alder caused by genetic mechanisms is now unknown, work ith other forest species indicates that many such traits are under genetic ontrol (Campbell 1964, Dorman 1976). Fortunately, studies to provide some stimates for heritability of various traits in red alder are now underway n the Pacific coast. The biological aspects and alternatives to be onsidered in a genetic improvement program for alder are discussed by tettler (1978).

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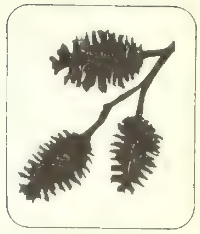
BIOLOGICAL ASPECTS OF RED ALDER PERTINENT TO POTENTIAL BREEDING PROGRAMS



REINHARD F. STETTLER, Professor of Forest Genetics
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

After a brief introduction to general concepts of genetic improvement, I discuss selected biological factors of red alder (Alnus rubra) *affecting the feasibility and direction of potential breeding programs. These factors include the diversity of the genus, the species' life history, growth, reproductive biology, and nitrogen fixation. Because of its early sexual maturity, annual seed crops, and rapid juvenile growth, red alder promises to offer comparatively large genetic gains per unit of time and effort. Three alternative improvement programs with different emphases appear meritorious, i.e., (1) short-rotation fiber production, (2) normal-rotation log production, and (3) nitrogen production. Pending genetic improvement, information is needed on basic genetic parameters and on silvicultural techniques of intensive management.*

Introduction

The application of genetic principles to the improvement of forest ees is encompassing an ever-increasing number of species in the major rest regions of the world. What initially was tried on a small scale with handful of commercially important conifers has become accepted as a gen-al approach to raise forest productivity in quality and quantity, in a de array of conifers and hardwoods.

Genetic improvement of a species is a form of regulating its variation ward a set of goals. Since this set is only a small subset of the cri-ria to be met under natural selection, the gain in desired variation is ten tangible already in the first or second generation of controlled eeding. This gain, however, exacts a price. Part of the price is quite raightforward and comes in direct costs associated with improvement pro-ams. Yet, even in this narrow framework, a cost/benefit assessment is ndered difficult by the arbitrary nature of economic models, the alterna-ves considered as comparisons, and the reference units of time adopted. other part of the price is paid in even less tangible currency, such as creased flexibility in organizational commitments, increased dependence

on specialized markets, regulatory constraints and their enforcement, the need for policy coordination among regions and countries, etc. But perhaps the least well understood price for genetic improvement is the biological one. The goals adopted in breeding are, by definition, anthropocentric and they can be reached only with a concomitant change in gene frequencies, the ultimate impact of which may only be measurable generations hence.

We might, thus, view tree improvement as a form of domestication in which certain attributes and values of trees are enhanced at the expense of others and in which a strategy is adopted for minimizing risks of maladaptation, and providing for potential changes in what is deemed desirable. For the planning of this process, the collective experience from agricultural plant domestication is a valuable, if insufficient, source of information. Trees, after all, have unique life histories and occupy a unique position in our ecosystems. Species-specific research and region-specific monitoring will be the only way to set the course and judge the merits of long range tree improvement.

The global awakening of interest in the genetic manipulation of forest tree populations has also been witnessed in the coastal Pacific Northwest. As in other regions, early attention was given to studying seed-source variation in the most prominent species; in this case, Douglas-fir. Eventually the emphasis was shifted to individual-tree selection and progeny testing; and by the mid-sixties, major commitments were made to operationally produce superior planting stock from selected parents in seed orchards. At that time, parallel, if less substantial, programs were initiated with western hemlock, Sitka spruce, and even noble fir. We may now ask: are conditions now favorable for such an undertaking with red alder? Or more specifically, what are the potential benefits we might derive from a purposeful breeding program of red alder?

There are many aspects that have a bearing on this question. In this paper, I will confine myself to a brief review of several biological factors that intrinsically affect the nature, direction, and success of potential breeding programs of red alder.

The Genus

DISTRIBUTION AND TAXONOMY

The genus *Alnus* is widely distributed, primarily in the temperate and cooler regions of the northern hemisphere, but also extending into the southern hemisphere along the Andes. Although hardly predisposed for rapid evolution, the genus contains a remarkable diversity of species, some, as *A. cordata*, having adapted to the Mediterranean climate, others, as *A. nepalensis*, to the harsh conditions of the Himalayas, some remaining shrubs, others growing into trees and successfully competing with the fastest growing conifers.

Murai, in his taxonomic studies of the genus *(24)*, recognized 29 fferent species, grouped into two subgenera with two and five sections ch. More recently, Furlow (*10*), based on a detailed study of the American xa of *Alnus* using morphological, anatomical, palynological, and chemical ta and involving both traditional and numerical taxonomic procedures, has oposed a different scheme. Perhaps the most important changes he has ggested are the recognition of three rather than two subgenera (i.e., *nus, Alnobetula,* and *Clethropsis*) and the conspecific[1] status of four erican taxa with Eurasian species (i.e., *Alnus incana* subsp. *rugosa, A. cana* subsp. *tenuifolia, A. viridis* subsp. *crispa,* and *A. viridis* subsp. *nuata*). Furthermore, Furlow has emphasized the need for a comprehensive xonomic revision of the entire genus, based on unified taxonomic concepts d up-to-date information, to reduce the current confusion in the treatment taxa and the concomitant proliferation of specific and intraspecific mes.

Chromosome Numbers

Evolution of chromosome numbers has been quite conservative in the genus (*24*). rtually all species analyzed have a somatic complement of 2n = 28, with the ception of two Japanese alders (i.e., *A. Sieboldiana,* 2n = 56; and *A. firma,* = 42). A somatic number of 2n = 14 was reported for *A. Inokumae* by Chiba), leading to phylogenetic speculations (*25*), and pointing to the presum- ly derived nature of the 2n = 28 number. Furthermore, in at least seven ecies with 28 chromosomes, occasional individuals have been found with ther 2n = 42 or 56, suggesting spontaneous polyploidization.

BRIDIZATION

Natural hybrids are commonly found in alder wherever the geographic nges of two taxa overlap (*10*). This is particularly true when the two xa are closely related, as in the case of *Alnus crispa* subsp. *crispa* and *incana* subsp. *sinuata* in Alaska, or in the *A. incana* subsp. *tenuifolia* - *gosa* complex. Besides, many artificial hybrids have been produced in var- ous parts of the world. A summary of reported interspecific hybrids com- led by Murai (*24*) lists a total of 26 different combinations, half of ich are intrasectional, half intersectional. Several of these hybrids ow good growth, among them the hybrid between *A. rubra* and the Eurasian *A. lutinosa* (*20*).[2]

In an effort to elucidate crossability patterns within the genus, gman (*12, 13*) studied barriers in crosses between *A. incana and A. gluti- osa*. He found interspecific incongruity[3] to be expressed by the retarded

[1]Conspecific = belonging to the same species.

[2]The cross *A. rubra* x *A. glutinosa* was also made by L. Karki in 1951 at the University f Washington in Seattle, and several hybrid specimens are still growing in the University f Washington Arboretum.

[3]Interspecific incongruity refers to the lack of functional affinity between two pecies as manifested in their inability to successfully hybridize. It is attributed to ifferences in many genes as a result of evolutionary divergence.

pollen-tube growth of foreign pollen in the style, a phenomenon also encountered in birches. Similar results were recently obtained by Millar (in experimental crosses between *A. rubra* and three other species of alder, i.e., *A. cordata, A. glutinosa*, and *A. sinuata* (or *A. viridis* subsp. *sinu* according to Furlow, (*10*)). Taking intraspecific crosses in red alder as standard, she found pollen tubes of all interspecific crosses to be signif icantly slower, and more so with decreasing degree of relatedness (i.e., crosses with *A. sinuata* gave the lowest figures). She also found significant differences between reciprocal crosses, between conspecific individu and between years.

The Species

LIFE HISTORY

Red alder has typical characteristics of an early successional speci Its abundant and light seeds are easily dispersed; being short on nutrien however, they need a favorable seed bed--typically, exposed mineral soil-- get established. The established seedlings enter a phase of phenomenal height growth associated with keen competition and sharp reduction of ste numbers per unit area due to mortality. Sexual maturity is reached as ear as age 3-4 in individual trees, and 3-4 years later in the majority of do nant trees in a stand. Thereafter, seed crops are produced annually, wit bumper crops every 3-5 years. Height growth begins to decline after 20-3 years, and maturity is reached at 60-90 years. Little, if any, advance re generation by alder can be found under a mature canopy, it takes some ope ing, a minor disturbance, or the like, to get the next generation starte

Thus, as forest trees go, red alder is a good example of what population biologists describe as an "r-strategist." This term refers to one o two demographic parameters, r (for growth rate), and K (for population si in the basic equation of the logistic growth curve of populations (*21*). demographic trends are compared among different species, it seems that di ferent life-history strategies have evolved that can be described in term of r and K. Opportunistic species, or "r-strategists," seem to channel their energy in such a manner as to quickly discover a habitat, rapidly re produce to use up the resources before competing species exploit the habitat, and disperse to new habitats as the existing one becomes inhospitabl By contrast, "K-strategists" are better capable of holding on to a habitat and extracting the energy produced by it. They seem to achieve this through longevity, competitive ability in suppressing other species while maintaining a population under limiting conditions, and successive replacement of dying members from a continuous but modest supply of propagu (*35*).

One may view these terms merely as a facelift for such familiar conce as pioneer vs. climax forest, intolerant vs. tolerant species, colonizers vs. residents. Perhaps the significant change, however, are the followin general recognitions. (1) Life histories are strategic programs of environmental tracking, embodied in the gene pool of a species, and subject t

ural selection. (2) While we may speak of a species' strategy, we should ew it as a population phenomenon with a greater or lesser amount of inher- variation. It is this variation from which evolutionary changes in demo- phic parameters are derived. (3) Each life history is a composite of co- pted processes; a change in one results in correlated responses of others.

It is these "r" characteristics to which we can attribute the rapid ex- sion of red alder populations within the last century. It seems that the rent abundance of alder has been virtually unprecedented in the post-gla- l history of the Northwest, as judged by pollen-sediment studies (*14, 7*), that it is due largely to the effective colonization of areas disturbed man. We may visualize this process as a series of successive colonizing nts following man's activities, each colonized area serving as the unching pad" for the next one. With early seed production in alder, this cess may well have involved five to six successive generations over the t 100 years, each of which being subject to intensive selection for "r" its, and the resulting populations being particularly rich in these racteristics. We should keep this in mind when we consider establishing tificial selection programs for red alder, particularly with reference the selection goals we choose and the gains we expect.

DWTH

Little needs to be said about growth and yield of red alder since this pect is well covered in these and previous proceedings (*32*). It may be rely emphasized that red alder, among Pacific Northwest trees, is second ly to black cottonwood in juvenile height growth and that its growth and eld compare favorably with other alder species, although quantitative ta are lacking to substantiate this point, particularly under Pacific rthwest conditions.

PRODUCTIVE BIOLOGY

Reproduction by Seed

Red alder is commonly monoecious--male and female flowers being borne separate but proximate aments. Deviations from this norm have been re- ntly found by Millar (*23*) in several alder species in the form of pistil- te aments carrying several functional anthers at their base. In 1977, the equency of these bisexual aments ranged from 0.5 to 2 percent per tree for sample trees in red alder, and was in the same range for fewer sample ees in *A. glutinosa* and *A. cordata*. Deviant aments were found in every ee sampled. By contrast, no deviations had been observed in the preced- g year (*23*). Such year-to-year fluctuations in sex expression have been ported for other genera, also in dioecious species, and are being viewed day by evolutionary biologists as one of the adjustable variables in the aptive strategy of plants (*1, 17*). In the case of monoecious alder, how- er, such a minor shift toward increased maleness should hardly make an pact on the prevailing mating system since, even under normal conditions, llen is abundant, and self-pollination is facilitated by the proximity of le and female organs.

Are there barriers to selfing? Asynchronism between male and female flowering on the same individual seems to be operative in red alder only to to a minor degree if the small sample studied is indicative of the populations at large (*23*). Peak pollen shedding preceded peak female receptivity by no more than 2-4 days, with sufficient overlap of timing for selfing to occur.

Artificial selfing has been conducted in several alder species with variable success. Most of this work was done with *A. glutinosa* and *A. incana* and seemed to show various barriers at work, from reduced pollen-tube growth to lower seed set, to reduced viability and subsequent growth of seedlings (*18, 22, 8, 12*). On the other hand, Heitmüller (*16*) found these two species to be self-fertile; and more recently, Weisgerber (*33*) has reported breeding studies with *A. glutinosa* in which 7-year height growth of certain selfed progenies was equal to or better than that of outcrosses. In 1972 at the University of Washington, we initiated a comparative study of selfing and crossing in red alder involving both normal and mutant trees of the *pinnatisecta* variety (*31*). The percentages of filled seed ranged from 46-4[illegible] in normal x normal crosses, 11-14 in selfings of both normal and mutant trees, and 0.75-1.6 in isolated aments having received no pollen (i.e., apomictic seed)[4] (*15*). Germination of filled seeds was higher in selfs (71 percent) and in apomicts (54 percent) than in outcrosses (42 percent), but survival and growth of seedlings during the subsequent 3 years favored the outcrosses. Browsing and other damage by elk obscured some of these comparisons.

The occurrence of agamospermy in red alder, as demonstrated in our experiments, is in agreement with earlier observations of this phenomenon in other alder species (*36, 12*). So far, the evidence shows that alder is capable of producing seed in the absence of pollen. It is not known yet through which of the several embryogenic pathways these apomictic seeds have come about, except for *A. rugosa,* where adventitious embryony[5] seems to be involved (*11*, Chapt. 18). But it is important to realize that the presence of pollen need not preclude apomixis (in fact, in pseduogamy,[6] it is a necessary prerequisite) and that, therefore, the actual proportion of apomictic seeds may be higher than we suspect. In other words, some of the seeds from controlled selfings or outcrossings may actually be apomicts.

It is of more than academic interest to be able to discriminate among these alternative classes of seed since they harbor different amounts and

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[4]Apomictic seed formation, or agamospermy, is the development of seeds without fertilization.

[5]In adventitious embryony, the embryo originates from a diploid, somatic cell of the ovule.

[6]In pseudogamy, pollen apparently delivers the stimulus for seed formation, but not the gametes.

itterns of variation. The *pinnatisecta* material in our red alder offers a nvenient marker for such an analysis, and experiments are planned to conct it as soon as the F_1s between normal and *pinnatisecta* trees are sexual- mature.

In summary, our limited information to date indicates that selfing and omixis are operative in red alder, but how extensively and consistently, do not know. The available data also suggest that the majority of seeds e most likely the result of outcrossing, a condition that is facilitated the aggregation of red alder, its annual propensity for flowering, and s wind-borne pollen.

Vegetative Propagation

Red alder has the ability to produce sprouts, particularly after some jury to the stem. It is one of the reasons why we find occasional clusters clumps of trees in natural stands. Under natural conditions, however, is cloning habit is only mild and seems less pronounced than that of paper rch (*Betula papyrifera*), let alone that of aspen (*Populus tremuloides*).

Artificial propagation can take advantage of this sprouting ability, ich seems to be higher in young trees than in mature ones (*19*). Recent periments have shown that coppicing of red alder can be successfully pured on a short-rotation basis, with excellent sprouting after the second rvest.[7] Techniques for the propagation of *A. glutinosa* and *A. incana* grafted scions and cuttings have been developed in Finland to the int where vegetative propagation offers a practical alternative to the aring of plants from seed[8] (19). More than likely, these techniques n also be successfully applied in red alder.

TROGEN FIXATION

The nitrogen-fixing ability of alder has received increasing attention er since (1) it has been shown that nitrogen is a limiting factor for tree owth on many forest sites, and (2) the costs of industrial nitrogen proction in the form of ammonia have soared due to the dwindling supply of ssil fuels. The latter fact has led to a global awakening of interest in l forms of biological nitrogen fixation; and judging by several symposia d reviews, a remarkable burst of research activity has taken place in this main in recent years (*28, 26, 27, 5, 9*).

Many novel approaches to creating new or improved nitrogen-fixing biogical systems have been proposed (*9*). At the same time, it has become parent that in the systems studied, the biological machinery involved in

[7]DeBell, D.S. Forestry Sciences Laboratory, Pacific Northwest Forest and Range xperiment Station, Olympia, Wash. Personal communication.

[8]Lepistö, M. Personal communication. The Foundation of Forest Tree Breeding, inland.

nitrogen fixation is highly complex and under the control of many genes in both host and symbiont. But, by comparison with the well-studied legume/*Rhizobium* system, the biology of nitrogen fixation in alder is still poorly understood. Several facts have emerged that have a bearing on genetic improvement of alder; they may be briefly enumerated:

1. All alder species are capable of acting as host for nitrogen-fixing endophytes (*4*).

2. Extensive surveys, involving thousands of trees of mainly *A. incan* and *A. glutinosa* in many countries, have shown all trees examined to be nodulated (*4*).

3. Rates of nitrogen fixation may be remarkably high (150-300 kg N/ha yr.) compared to many other non-legume symbioses. In species such as *A. incana* and *A. viridis,* these rates exist under stringent conditions of high altitude or latitude (*30*).

4. The accumulated nitrogen contributes significantly to soil fertility and benefits growth of associated species such as *Picea, Pinus* *Populus,* and *Pseudotsuga* (30).

5. Root biomass in *A. glutinosa* has been shown to be significantly different among provenances in a controlled study (*29*). A larger root volume provides more host substrate for nodulation.

6. Active nodules are metabolic "sinks" for photosynthetic products in the host plant (*34*). Rates of photosynthesis, respiration, and translocation, as well as the partitioning of photosynthates among alternative sinks, are host factors affecting the rate of nitrogen fixation.

7. The endophyte belongs to the symbiotic actinomycetes but has yet to be isolated and cultivated on artificial media (*2*). It, however, exists in a number of forms, each capable of symbiosis with a restricted number of host species (*3*).

Genetic Implications

OPPORTUNITIES FOR GENETIC IMPROVEMENT

Red alder harbors a vast amount of variation, as one would expect from a species with such an extensive latitudinal distribution. By inference an by analogy with other species covering a similar range, we can surmise that much of this variation is under genetic control. Results from a small provenance test, established by Douglass and Peter in 1968 with 10 seed sources support this expectation (see DeBell and Wilson, these proceedings). Furthermore, a recent study has shown substantial phenotypic variation among trees within a stand (DeBell and Wilson, these proceedings). The amount as well as the pattern of this variation seems to be consistent with what we would expect from a species with extensive populations, even-aged stands, synchronous flowering, effective pollen and seed dispersal, and a breeding system that favors outcrossing.

Since the success of selective breeding depends on the amount of genetic riation available, we can say that red alder offers plenty of raw material r genetic improvement.

Additional variation may be made available from other alder species by y of hybridization. The most promising candidate for this purpose would the closely-related *A. glutinosa*; other likely choices would include *A. ombifolia* and *A. incana*. More distant crosses, although eventually feasible, are less likely to result in successful hybrids, due to disharmony of nomes. Barriers to gene transfer will be operative even among closely lated species but may not be insurmountable.

RECTION OF POTENTIAL IMPROVEMENT PROGRAMS

Three avenues with different emphasis appear promising:

1. Short-rotation fiber production. Emphasis would be on rapid juvenile growth, desirable fiber properties, abundant sprouting after mechanized coppicing, and adequate nitrogen production to prevent rapid depletion of soil fertility. The most suitable stock for this purpose would probably be found among the younger stands in the most recently colonized areas after disturbance, representing the result of several past cycles of r-selection. The short rotation would permit the use of clonal mixes, combining intensive selection with vegetative propagation.
2. Normal-rotation log production. Emphasis would be on sustained volume growth, good stem form and branching characteristics, moderate seed production, and wood properties consistent with utilization needs. Recruitment of suitable stock would best be undertaken in currently mature alder stands presumably having experienced less r-selection pressure. Plus trees would be progeny tested and grafted into clonal seed orchards where seed would be produced for production plantations. An alternative option would be to conduct mass selection by leaving the best trees as seed sources for natural regeneration.
3. Nitrogen production. Emphasis would be on the role of alder as site improver, admixed to or alternating with conifers or black cottonwood. Desirable attributes would be all those associated with maximizing nitrogen production in a form most suitable for alder and/or companion species in either a short- or long-rotation time frame. Suitable stock may be found displaying good growth on poor sites and in climatically extreme conditions unfavorable for nitrogen fixation. Clonal testing and propagation would eventually be combined with selection of superior endophyte strains in an effort to produce synergistic pairs of host and symbiont.

(PECTED GAINS

At this time, no heritability estimates are available on selected raits of red alder to permit specific predictions on the potential gains

to be realized from selective breeding. If we compare alder, however, with other Northwest species with active genetic improvement programs (e.g., Douglas-fir, hemlock, ponderosa pine, western white pine), we cannot help but be optimistic about its potential response to genetic manipulation. In fact, for several reasons, it may well be the species of the region most ideally suited for rapid genetic gains per unit of time and effort, because:

- it reaches sexual maturity unusually early;
- once mature, it produces annual seed crops;
- its rapid juvenile growth, combined with short-rotation management, permits an early assessment of qualitative and quantitative selection criteria;
- more than likely, it presents little problem for vegetative propagation.

For maximum genetic gains, selective breeding with progeny-tested parents will be prerequisite. Less spectacular gains can be expected from seed collection in superior stands.

Outlook

Red alder is the most abundant commercial hardwood in the Pacific Northwest. It has a number of features--rapid juvenile growth, multipurpose wood properties, nitrogen-fixing ability--that make it truly a regional asset. Its mature dimensions and quality compare favorably with those of other alder species here or elsewhere. Yet, it still exists in a wild state. Judging by the domestication success of mass selection in the European *A. glutinosa,* the potential gains from selectively breeding red alder are unusually high.

Whether genetic improvement programs are deemed feasible, and if so, at which level of commitment, will be largely decided by extrinsic factors associated with the economics of the forest industry. It is safe to say, though, as our region is gradually emerging from an exploitative forestry and as we are becoming more energy conscious, that the spectrum and diversity of forest-tree species encompassed in intensive management will be systematically broadened and will eventually include red alder.

In the meantime, the need for certain information can be anticipated. Two broad categories may be distinguished:

1. Basic biological information: e.g., the assessment of natural variation in growth, yield, quality, and wood properties and its partitioning into genetic and environmental components through provenance, progeny, and clonal tests. Special efforts should be directed at measuring genetic variation in the major variables affecting nitrogen production in both host and endophyte.

2. Information on silvicultural techniques of intensive management: This encompasses all aspects from the propagation and establishment

of planting stock to the harvesting of alder plantations under both short- and long-rotation schedules. Of equal importance is information on silvicultural treatment of natural stands toward increased quality and productivity.

In view of competing information needs on conifers, it is unlikely that omprehensive research effort on alder will be made by any one agency at s time. Rather, we will see a scattering of individual studies reflect- different priorities and commitments. It may be useful, therefore, to sider organizational mechanisms that would serve to coordinate these indi- ual efforts and ensure balanced progress.

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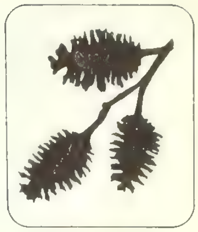
HERBICIDES IN ALDER MANAGEMENT AND CONTROL[1]



MICHAEL NEWTON, Professor of Forest Ecology
Department of Forest Science
School of Forestry
Oregon State University
Corvallis, Oregon

ABSTRACT

Herbicides can be used effectively to convert alder/shrub communities to conifers, to release conifers from such cover, and probably to prepare sites for alder production. To thin and cull young stands of alder, trichlopyr (not yet registered), 2,4-D amine, and cacodylic acid can be effectively injected into selected trees. In conifer management, alder and associated species can be controlled with (1) 2,4,5-T before bud burst (the best release tool), and (2) brushkiller (2,4-D + 2,4,5-T) in late summer (best for release from alder, hazel, thimbleberry, cherry, and ocean spray).

To convert brushfields, the initially expensive brown-and-burn procedure is most successful. In site preparation, phenoxys (2,4-D and 2,4,5-T) alone often require multiple treatments and often result in heavy animal use. Krenite ®, picloram/phenoxy mixtures, and glyphosate (registered in Oregon only in 1977) are satisfactory if treated stems larger than 3-in diameter are felled and large seedlings, preferably less palatable species, are used.

Introduction

Herbicides kill or control the growth of plants. An indirect and ex-remely useful result, however, is the release of site resources--resources hat otherwise would be dominated by competing weed species--for the benefit f crop plants. We use herbicides as silvicultural tools to remove or create ndesirable habitats for those plants that interfere with the trees we are rying to grow. Regardless of the species to be grown, we can apply the erbicide either before the desired species is established (site preparation) r after the crop trees are established (release) to promote their growth.

Herbicides have not been widely used to deliberately promote the growth

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and development of alder stands. Most of the concepts gleaned in conifer silviculture can, however, be adapted directly to alder culture. Obviously the applications must be different although the same chemicals can be used; different species may be promoted or controlled simply by changing the application method or timing.

To elaborate on the use of herbicides in alder management, I must draw heavily on my own experience and synthesize that experience with extensive unpublished data. Also, I will extrapolate to alder some of the unpublished experiences of others working with cottonwood and yellow poplar.

Alder Site Preparation

In the Pacific Northwest, virtually no research has focused on chemical site preparation to establish alder in brushfields. My cooperative work wi Publishers Paper Co. and Starker Forests has, however, provided data from conifer site preparation studies that should apply directly to alder. For these studies, several herbicides including glyphosate were applied during August and September of 1975 and September of 1976.

Glyphosate alone had properties that would help establish alder. That is: 1) Glyphosate left no residue in soil; 2) glyphosate controlled virtually all non-evergreen vegetation, including brush and herbs; and 3) glyphosate did not scarify the soil, thus preventing establishment of excessive alder stocking or weed vegetation. Establishment of alder requires control of herbaceous vegetation; and glyphosate controls deciduous brush totally and temporarily controls herbs. Site preparation with glyphosate would be appropriate only for plantations with poor seed bed conditions for natural regeneration.

Glyphosate is a strange compound. Plant responses to it are very different from the responses to phenoxys (that is, 2,4,-D and 2,4,5-T), and the differences show up in surprising ways. Glyphosate acts on root system as well as tops, and root failure is extensive by the time tops develop symptoms. Basal cankers show up on some sensitive species before defoliation is complete. During the year or more a plant may take to die, it may produce considerable foliage, despite glyphosate activity being the result of foliage uptake. Many evergreen plants are almost totally resistant whil dormant. To add to the paradox, understory vegetation is extremely sensitive, and three-fourths of a pound of glyphosate (one quart) per acre produces a nearly clean understory through a very dense canopy of 15-year-old alder. Strangely, broadcast application of the glyphosate before mid-Augus only slightly injured existing alder. Application of 3/4 to 1-1/2 pounds of glyphosate (active acid equivalent) per acre between early August and late September will completely kill salmonberry, bracken, hazel, ocean spray, vine maple, cascara, bitter cherry, and virtually all herbs. Earlie application will control herbs, but brush may recover. A comparison of tim for effective and safe application of glyphosate and other herbicides (fig. 1) suggests that variation of the application date strongly affects the relative sensitivity of alder and conifers.

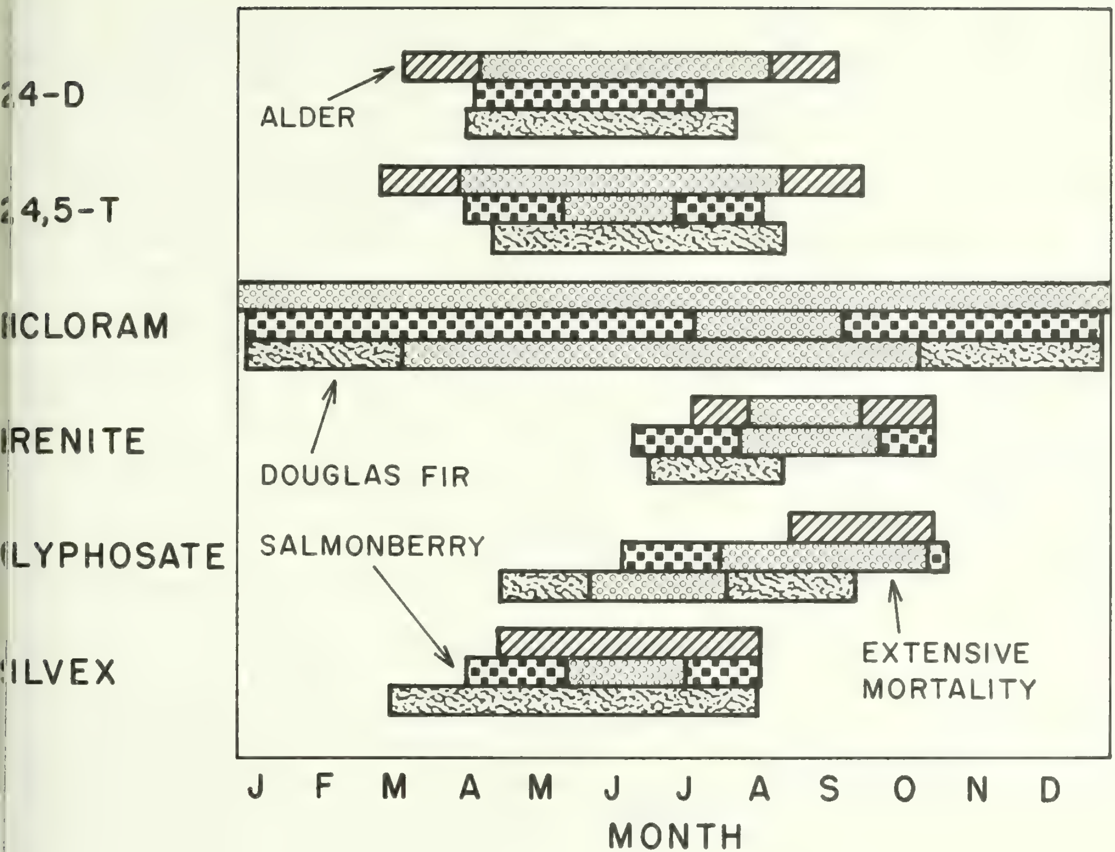

Figure 1.--Periods during which brush control herbicides injure alder, salmonberry, and Douglas-fir. Solid line indicates extensive mortality.

Thus, glyphosate apparently may be used selectively to clean alder rowing in mixed stands or to clean understories in pure stands as an aid harvesting and preparing for the next crop. It may also be used to con-rol general vegetation and to prepare a site for the planting of alder or nifers.

Because glyphosate is extremely expensive now and its registration is pending, I will look at some alternative chemicals that may prove useful to establish alder. Data are largely limited to herb control trials. Two herbicides, simazine and dichlobenil, may help control herbs in plantations. Dichlobenil is registered for use in nurseries and with ornamental cultures of various hardwoods. Dichlobenil also can be used to control numerous herbs such as bentgrass that are commonly associated with alder in open coastal habitats. Simazine injures some hardwoods but not others. In Ontario, the Canadian Forestry Service has successfully used simazine in combinations with glyphosate for aspen regeneration. Simazine tends to remain in surface soil out of the reach of planted roots. Because of its adverse effects on new germinants, I do not recommend simazine for direct seeding.

Krenite® is now registered for use in forest site preparation. It injures alder through foliage, but leaves no soil residue. In general, Krenite® does not control herbs, and it is relatively ineffective on elderberry. It is most suitable where pure salmonberry impairs successful site preparation.

Alder Stand Improvement

Few natural stands of alder have ideal stocking or distribution of trees. Chemicals can be used to improve the manageability of such stands. Broadcast treatments are seldom safe, and established alder is sensitive to many brush killers applied that way. For alder thinning and culling, however, selected trees can be injected with one of several herbicides that are highly effective yet safe for the residual stand. The well-tried 2,4-D amine, injected undiluted at the rate of 1 ml per inch of diameter, is very effective when applied between mid-June and September. Similarly, a mixture of Tordon 101® and 2,4-D amine at the same rate is effective from April to October; and Tordon 101® alone is effective any time. Trichlopyr, not yet registered for this purpose, is effective at full strength from September to November. In the spring, do not try to control adler with 2,4-D amine or with the organic arsenicals, MSMA (monosodium methanearsonate) and cacodylic acid. In the early summer, 2,4-D amine is most effective, while the arsenicals are most effective in October. Cacodylic acid is more effective than MSMA on alder, but MSMA is a better all-around herbicide for tree injection.

Of the effective chemicals, only cacodylic acid and 2,4-D amine are known to be nearly free of "backflash" damage to untreated trees due to herbicide translocation via root grafts. Picloram, one of the active materials in Tordon 101 ®, has a pronounced tendency to "backflash" and to remain active in soil for 6-12 months. This poses a problem in alder where the specific activity of picloram is extremely great. The residue from hardwood control appears to be a minor problem for the management of conife[illegible]

Broadcast applications of glyphosate show promising signs of being able to control brush and other hardwoods mixed with alder. Application of three-fourths of a pound or less of active glyphosate (one quart) per acre

ring August causes negligible injury to alder, but will severely injure arly all other deciduous shrubs and cherry. Evergreen shrubs and hardwoods pear resistant.

Release of Conifers

Thus far, I've emphasized the use of chemicals to promote the growth of der. When the virtues of alder are mixed blessings at best, we may be rced to use chemical silvicultural tools in order to capitalize on those sets. The observation that alder can fix up to 300 pounds of nitrogen r acre per year on nitrogen-deficient subsoils offers clear incentive for ving alder and conifers co-exist on such sites. That ability to fix trogen, however, is combined with rapid juvenile growth that will suppress nifers established at the same time. Therefore alder must be grown so it n fix nitrogen, yet it must be controlled in time to protect the conifers, e beneficiaries of fixation. Release does just that.

Selective control of alder and associated species in coniferous planta- ons is quite simple and inexpensive. The phenoxy herbicides, 2,4-D and 4,5-T, have been used for this purpose for nearly 20 years with moderately od, if not outstanding, success. Selectivity with the phenoxys is strongly pendent on season, (fig. 1). Consequently, the spring dormant spray sea- n, shortly prior to conifer bud burst, is the best time to control alder th minimum damage to conifers. Good selectivity is also achieved in early gust. If the phenoxys are applied between the time shortly after bud rst and summer bud set, damage to conifers--sometimes severe--can occur; t trees usually recover in 1-3 years with no permanent injury.

The choice of herbicide depends on the season it will be used, the spec- rum of species to be controlled, and its registration status. During the rmant season, 2,4,5-T is normally the most effective phenoxy when applied a straight diesel fuel carrier. Addition of water substantially decreases e effectiveness of the mixture, whether as an invert emulsion or a normal ulsion; water sets up an absorption barrier at the bark surface that de- reases the penetrability of the oil-based ester. Oil substitutes are nei- her available nor pending. Adding 2,4-D to the 2,4,5-T does not increase effectiveness during the dormant season. In fact, the use of 2,4-D plus ,4,5-T mixture has repeatedly proven less cost-effective than 2,4,5-T alone en applied to coastal brushfields during the spring dormant season. This s particularly true when vine maple and salmonberry are to be controlled.

Release sprays consisting of a mixture of 2,4-D and 2,4,5-T are more ffective in August than during the spring dormant spray season. In August, pplication to each acre of 1 pound of each ingredient in water provided ood control of alder, bitter cherry, hazel, ocean spray, and thimbleberry.

After the buds burst, spraying early foliage with a mixture of 2,4-D nd 2,4,5-T in water provides some control, yet uses no oil. At least one ublic agency follows this procedure. Empirical evidence, however, shows hat conifer injury is greater than with earlier treatments and that sprout-

ing species recover quite rapidly. Not everyone agrees with this analysis, but I believe that the earlier and later treatments are more selective thar post-bud burst spraying which may require several repeat applications.

The most remarkable selectivity I have observed in my years of forestr herbicide research is manifested by glyphosate in brush-threatened conifer plantations. In conifer silviculture, aerial sprays of glyphosate (1-1/2 pounds or 1/2 gallon product per acre) that leave Douglas-fir and Sitka spruce nearly unscathed will control grasses, broadleaf herbs, bracken, blackberry, thimbleberry, salmonberry, hazel, vine maple, ocean spray, bitter cherry, alder, and possibly bigleaf maple. Glyphosate injury to cor ifers, when it does occur, does not seriously inhibit growth during the nex season. In contrast, the injury to deciduous species other than alder appa ently continues until the eventual death of the trees. Application of 3 pounds active glyphosate (1 gallon) per acre causes significant damage to Douglas-fir and moderate to severe injury to hemlock, but only minor damage to spruce; that same application kills virtually all ground cover (includir sword fern) except salal. Thus glyphosate serves both as a release treatment (at 3/4-1 pound active or 1-1-1/3 quarts of products per acre) and as a site preparation treatment at somewhat higher rates.

Conifer Site Preparation

Site preparation entails more complete vegetation control than does release. Release only requires that established conifers be thrust above the competing canopy at a time of development when they can be expected to grow rapidly; in contrast, site preparation calls for intensive control of vegetation so that later release is unnecessary. When discussing long-tern control of alder, we must consider the inevitable association of alder witl salmonberry and other understory shrubs.

Krenite® has now been registered for use in reforestation areas for site preparation and release. Application of an aqueous solution (3-5 pounds of the active ingredient per acre) during September will simultaneously kill alder and salmonberry; unlike the phenoxys, Krenite® kills salmonberry roots. The same application also controls vine maple, hazel, ocean spray, bitter cherry, and perhaps other deciduous shrubs. However, control of all species decreases if application is earlier or later than September. Evergreen species are resistant; elderberry and thimbleberry ar resistant to lower dosages. Because Krenite® can injure conifers, especially hemlock, it must be used with careful control of dosage for release

Krenite® is an excellent site preparation treatment for use near wate ways and scenic areas. It acts slowly, and quite specifically, on certair target species, especially salmonberry. A September application effects nc obvious change in foliage until normal abscission. No brownout occurs; instead, by the next spring, the landscape looks like a gray haze of dead twigs with a green background of ground cover that survives with little injury. Krenite ® is virtually nontoxic to fish and other wildlife, and the surviving ground cover tends to remain in good condition for big game and

ter terrestrial fauna. Because Krenite® is a poor desiccant, the treated etation can not be burned readily.

The phenoxy herbicides alone simply do not do a good job of controlling shrubs with an alder overstory; however, picloram plus 2,4-D or 2,4,5-T vides broad-spectrum brush control with some residual effectiveness. In site preparation studies, we have recorded significant height increases 5-year-old planted conifers after site preparation had included a mixture picloram with the phenoxys. We attribute this to the residual effect of loram on the sprouters and to the broader spectrum of species controlled h picloram. Without picloram, phenoxys inhibit many roots only slightly. high productivity of the coastal soils, combined with resprouting abilis of several species, promotes the rapid recovery of mixed brush that is te difficult to control with phenoxys. That situation considerably rees opportunities for later release.

Standing dead alder will eventually fall and crush planted conifer seedngs. When Douglas-fir is planted, all alders more than 3 inches in diamer should be felled. Hemlock can tolerate slightly larger alder. The nding alder may be felled after planting the conifer, but only if alder no leaves. Virtually no living residual alder is tolerable in a new ntation.

In preparation of an alder-dominated locale for reforestation with conirs, one must also consider how the nitrogen-fixing ability of the alder, the consequently high fertility of the surrounding soil, have enhanced wildlife habitat. When alder is removed by most chemicals, shelter and od supplies for wildlife remain abundant, and animal populations appear to uilibrate with the changed, and often improved, habitat. As the populaons respond, mountain beaver, hares, and brush rabbits may severely damage conifer regeneration. Animal populations probably will not increase if ground cover, as well as the alder, is removed with a broad-spectrum rbicide such as glyphosate. Such a treatment almost certainly precipites a temporary drop in the carrying capacity of the site. The decreased od supply, however, may cause the existing animal populations to feed on ything, including newly planted conifers during the first few months after plication of the herbicide; late planting may be advisable. Although all mammals will be a less severe problem if the cover is burned, the eared areas could be used as pastures and rearing areas by deer and elk. us, any site preparation operation relying on chemicals can result in rious animal damage problems. Consequently, the seedlings to be planted ll be less vulnerable if they are not small or highly palatable. Our data dicate that Sitka spruce, hemlock, and grand fir are well-suited to such tes. If Douglas-fir is used, it should be the largest size available, eferably more than 24 inches in height.

Discussion of site preparation must include "brown-and-burn," a techque effectively used on coastal sites supporting mixed brush types. Burng compensates substantially for the specific control capacity lacking when nventional herbicides are used.

In brown-and-burn, the larger brush and hardwoods are slashed early i summer, then a systemic herbicide is applied to the brush. In late July o August, after the preliminary herbicide has translocated to the roots and suppressed growth of the vegetation, a desiccant such as dinoseb is applie to the remaining green vegetation. After the desiccant has dried the vegetation for 10-20 days, the entire area is burned.

Brown-and-burn is a very expensive, but highly effective, procedure. It also is moderately hazardous during slashing, during application of dinoseb (a relatively toxic herbicide), and during burning. In addition, smoke control programs limit the opportunities for burning so that numerous desiccated areas resprout new vegetation before the area can be burned.

Brown-and-burn does have some advantages. By clearing the ground, thi procedure not only reduces planting costs, but also substantially prevents much subsequent animal damage. Brown-and-burn reduces mountain beaver populations and temporarily eliminates rabbit and hare habitats. While minimizing costs per acre, large brown-and-burn projects also make much of an area temporarily undesirable for browsing by deer and elk.

Conclusions

Herbicides may be used to control or promote many types of vegetation. Careful regard for timing of application, dosage, and selection of chemical will determine what vegetation is killed. The degree of success in growing a desirable crop greatly depends on many other factors, especially choice of planting stock and animal damage. Careful attention to each step of the vegetation management process will insure maximum benefit per unit c cost, with minimum disturbance to the site.

SHORT-ROTATION PRODUCTION OF RED ALDER: SOME OPTIONS FOR FUTURE FOREST MANAGEMENT

DEAN S. DeBELL, Principal Silviculturist
Pacific Northwest Forest and Range Experiment Station
USDA Forest Service
Olympia, Washington

ROBERT F. STRAND, Senior Research Forester
Central Research Division
Crown Zellerbach Corporation
Camas, Washington

DONALD L. REUKEMA, Principal Silviculturist
Pacific Northwest Forest and Range Experiment Station
USDA Forest Service
Olympia, Washington

ABSTRACT

*Many options are available to foresters who may want to consider management of red alder (*Alnus rubra *Bong.). Four options are discussed in this paper — a coppice system and three high forest systems: pulpwood log, saw-log and peeler, and pulpwood log and saw-log production. Coppice can be grown on 4- to 6-year rotations and pulpwood logs can be produced in 10 to 15 years on most sites. Estimated yields (per acre per year) of these options are about double those obtained in natural stands. Saw logs and peelers can probably be grown in 28 to 37 years, and yields are estimated to be about 40 percent higher than those listed in normal yield tables for well-stocked stands.*

Introduction

The intent of our paper is to examine some options available to resters who want to consider management of red alder (*Alnus rubra* Bong.). ort rotations are essential for capturing the benefits of alder's rapid itial growth and the financial advantages associated with it; therefore, r paper will concentrate on short-rotation production systems. We will scribe four of several possible management options. Each option will be

discussed in terms of products, rotation length, spacings, and suitable locations or sites. We will also provide estimates of yield and discuss some of the special problems and limitations associated with each option. We have not attempted to analyze the costs and benefits of the options, nor have we made comparisons with conifer culture.

General Overview of Short-Rotation Options

The four systems selected to illustrate options for production of wood and fiber include a coppice or sprout system and three conventional, high forest systems: (1) pulpwood log, (2) saw log and peeler, and (3) a combination of the pulpwood log and saw log option which involves thinning. Table 1 summarizes the major aspects of each system--primary products, average size of tree at harvest, plantation spacing, and rotation length. Each system will be considered in detail in separate sections.

Table 1--*Summary of 4 options for short-rotation production of red alder*

System	Primary product	Average tree size at harvest		Spacing	Rotation length
		D.b.h.	Height		
		Inches	Feet	Feet	Years
Coppice	Barky chips	2	20 to 30	4 x 4	4 to 6
High forest	Pulpwood logs	6	45 to 47	9 x 9	10 to 14
High forest	Saw logs and peelers	14	81 to 95	17 x 17	30 to 38
High forest	Pulpwood logs and saw logs	6	40 to 43	8 x 16 to	9 to 12
		12	77 to 90	16 x 16	27 to 35

The Coppice System

The objective of the coppice system is growth of fiber for paper, other reconstituted fiber products, or energy. It consists of dense spacings of plants cut on short cycles, with regeneration by stump sprouting. The system was proposed for sycamore in 1966 by southern foresters (McAlpine et al. 1966). Soon thereafter, Smith (1968) suggested that such methods might be applicable for red alder in the Pacific Northwest. Subsequent evaluations by Schmidt and DeBell (1973) indicated that alder yields were favorable and satisfactory pulp could be produced.

YIELD ESTIMATES

We think the following specifications are reasonable for managing alder by the coppice system. Spacings of 4 by 4 to 6 by 6 feet would probably

appropriate for cutting cycles of 4 to 6 years--at least data for cotton-
od in the Northwest and sycamore in the Southeast point in this direction.
ands would be established initially with seedlings, but regeneration after
rvest would be by stump sprouts for several cutting cycles. At harvest,
e dominant sprouts would be 20 to 30 feet tall and 3 inches or less in
ameter. Yield expressed in terms of mean annual increment might vary from
to 6 ovendry tons per acre or approximately 200 to 600 cubic feet per acre.
tually, one could probably expect about 4 ovendry tons under a good system
management.

This yield estimate is based on two studies conducted at Crown Zeller-
ch: (1) an evaluation of productivity in dense, young alder thickets, and
) 2-year coppice yields from alder-cottonwood plantings spaced at 2 by 4
et. Details on these studies and the yields obtained follow.

Natural thickets.--Information on stocking, dominant tree height, and
an annual production in alder thickets of various ages is given in table 2
dapted from DeBell 1972). These data were collected from 28 small plots
by 6 feet) and averaged by age class. The plots were selected in thickets
extreme density and located in the lower Columbia River valley. Because
e data represent a highly selective population, interpretations must be
de with some caution. It appears that mean annual production can be very
gh in such thickets, especially at ages beyond 5 years. Production was
ghest for 7- to 12-year-old plots. This finding agrees with a report by
vitkovski and Stevens (1972) that mean annual increment peaks between ages
and 15. Our data also suggest that mortality is high in dense, young
der thickets. Stocking in 1- to 2-year-old thickets averaged 122,000 stems
r acre whereas 13- and 14-year-old stands had only 13,000 stems. Such
ss of wood through mortality could be minimized under intensive, short-
tation management. Growth could be concentrated on fewer, larger stems,
d maximum yields might be obtained at younger ages.

Table 2-- *Stocking and production in young alder thickets of various ages*[1/]

ge class	Stems per acre	Height of dominants	Estimated mean annual: Dry matter production	Estimated mean annual: Wood production	Number of plots
Years		Feet	Tons per acre	Cubic feet per acre[2/]	
1-2	122,000	6.0	1.89	100	4
3-4	64,000	12.2	2.35	130	9
5-6	35,000	16.2	3.54	190	7
7-12	17,000	27.3	6.85	380	5
13-14	13,000	32.6	5.91	320	3

[1/] These data are based on averages of individual plots on sites of varying stocking and productivity
thin each age class; they may not indicate actual trends with time in 1 stand.

[2/] Assumptions: Wood (minus bark and foliage) ≈66 percent of total production. 1 cubic foot of
endry wood ≈24 lb.

Alder-cottonwood planting.--Pure and mixed plantings of red alder and black cottonwood (*Populus trichocarpa* Torr. & Gray) were established in March 1973 on an alluvial site near Crown Zellerbach's pulp and paper mill in Camas, Washington. These plantings had a dual purpose: (1) to compare coppice production of alder and cottonwood at 2- by 4-foot spacing and (2) to test effects of pulpmill sludge and of irrigation on growth of the two species.[1] The plantings have been harvested twice, after the 1974 and 1976 growing seasons. Although the 1974 harvest yields were relatively low (average about 1.5 ovendry tons per acre per year), stumps sprouted vigorously in spring 1975 and the growing space was rapidly occupied by several shoots per stump. The resulting coppice growth harvested in fall 1976 (table 3) averaged 60 percent higher than the earlier harvest, and some cottonwood treatments compared favorably with short-rotation yields of species in other regions (see, for example, Steinbeck 1973 or Ribe 1974). Irrigation led to improved yields from both species; sludge benefited growth of cottonwood but had the opposite effect on red alder, perhaps because of the high supplements of nitrogen fertilizer added with the sludge. Alder got off to a slower start than cottonwood, and yields averaged about 40 percent lower than those of cottonwood. This finding parallels observations that cottonwood almost invariably outgrows alder under natural conditions. When no sludge was applied, alder yields were equal to those of cottonwood. Presumably, if spacing was widened and rotation length extended to 4 or 5 years, 4 to 5 ovendry tons of alder per acre per year could be produced. Perhaps the most interesting sidelights of the 1976 harvest were the higher yields obtained in mixed plantings (4.2 ovendry tons per acre per year) compared with yields in pure plantings of the two species (2.5 ovendry tons per acre per year) (table 3). This may be indicative of gains that might be obtained with mixtures of alder and other species in other production systems.

Table 3--*Effect of irrigation and pulpmill sludge on annual wood production from 2-year coppice*

Species	Irrigation	Sludge (tons per acre)		
		0	100	200
		Ovendry tons per acre per year		
Red alder	Yes	2.8	2.3	2.8
	No	2.5	2.4	1.9
Black cottonwood	Yes	2.8	4.3	6.1
	No	2.5	3.7	4.8
Mixed alder-cottonwood	No	4.2	--	--

[1]The sludge application included sufficient nitrogen fertilizer to bring the C:N ratio to 100:1.

SPECIAL CONSIDERATIONS

Concerns hindering immediate implementation of coppice management include efficient planting techniques, unknowns regarding sprouting capacity, harvest technology, and chip storage. Establishing large numbers of plants at dense spacings by conventional methods is costly, but perhaps costs would be acceptable if spacings were at least 4 by 4 feet with rotations of 4 to 6 years. Young alder stumps sprout vigorously, but sprouting of stumps of older saw-log size alder is not an effective means of reproduction (Worthington et al. 1962). Thus, there are unknowns regarding the number of times and the age to which alder stumps will sprout in a short-rotation coppice system. Harvesting still remains a source of concern, especially on wet, flood plain soils during the dormant season. Engineers believe the components for adequate systems are now available, but assemblage of a prototype harvester has yet to be accomplished. Degradation of chips during storage is also a potential problem; it may be resolved by immediate processing or by treatment if chips must be stored for several months.

The major obstacle to widespread use of the coppice system in the Pacific Northwest is the limited amount of suitable acreage. Production of total mill requirements by this system is probably precluded by limitations on land. A substantial increase (more than 10 percent) in fiber supply however, could be provided to some mills in the region. More important than fiber *per se* may be the use of densely spaced plantations for treatment of mill waste waters. Current environmental guidelines require zero discharge from mills by 1983. Whereas some companies are attempting to accomplish this by engineering advances within the mill, others are investigating the possibility of using intensively cultured plantations as a filter. With such a dual purpose, lease or purchase of highly productive agricultural land can probably be justified economically for coppice management--provided it is close to millsites.

High Forest Systems—General Considerations

High forest systems are management systems in which the crops originate from seedlings and the rotation is generally longer than that of coppice systems. High forest systems will probably play the greatest role in future production of alder in short rotations. Though planting and harvesting methods can be improved and tailored for alder production, existing techniques are usable and much more land is suitable for such management systems.

Given that rainfall is adequate for growth of alder, high forest systems may be applied to three types of land: (1) typical alder sites (stream bottoms, swales, and depressions in the uplands), (2) wet and/or deep soils now considered conifer sites, and (3) land where crop rotation is needed for correction of soil nutrient deficiencies or possible disease problems. Except in the last case where other considerations are involved, we believe that intensive, short-rotation management of alder should be considered only on lands having alder site indices of 90 feet or above at

mechanical site disturbance in order to minimize postlogging development o natural vegetation (including volunteer alder) may be desirable. Residual vegetation could be controlled by chemical means before planting, and on some sites control of vegetation after planting may be necessary. Suitabl techniques for postplanting control by chemicals, however, remain to be developed.

Although estimated yields may not be as high as those potentially possible with the coppice system, there are fewer unknowns in this more conventional approach to fiber production. Existing methods for harvest (e.g., small feller-buncher-forwarding systems) could be used provided pulpwood log production is limited to gentle, unbroken topography. Modifications that minimize ground pressure, however, are needed to reduce cos and limit site damage on the wet soils suited to alder production. The problem of storage is of less concern with this system because logs can be stored for longer periods than chips, and water storage can be used if necessary. Moreover, current log and chip processing facilities can be us

Saw-Log and Peeler Production

YIELD ESTIMATES

To illustrate possibilities for short-rotation culture of solid wood products, we have selected the following target stand:

Stems per acre	155
Spacing	17 by 17 feet
D.b.h.	14 inches
Height	81 to 95 feet
Average tree volume (CVTS)	35.5 to 41.5 ft^3
Total yield (CVTS)	5,500 to 6,400 ft^3

Trees would be initially planted at the wide spacing; no thinning woul be involved in this option. Heights and volumes per tree at rotation age would vary with site productivity; the taller trees would occur on the most productive sites. Rotation age and mean annual productivity also would differ by site as shown in table 5.

Table 5--*Rotation age and mean annual increment for the saw-log and peeler option, by site index*

Site index	Rotation age	Mean annual increment		
		4-inch top	Total stem	Total tree
Feet	Years	Cubic feet per acre per year		
90	38	140	140	200
100	34	160	170	240
110	32	180	190	260
120	30	200	210	300

Stand age at harvest could vary from 30 years on site 120 to 38 years site 90, with corresponding mean annual increments (CVTS) of 210 and 140 ubic feet per acre. By normal yield table predictions, it would take 41 to years (or 11 to 16 additional years) to grow trees of similar size in managed stands. Or, viewed from another angle, estimated yields would be bout 35 percent higher than normal yields at the suggested rotation ages r the target stand.

If tops and branches were chipped for reconstituted fiber products, otal yield per acre per year would range from 200 to 300 cubic feet.

PECIAL CONSIDERATIONS

Although it appears that saw log-veneer products could be produced in ess than three-fourths the time it takes in unmanaged stands, there are ome serious potential problems with this approach. Large tree size has een achieved by maintaining wide spacing throughout the rotation. Open-rown alder often develop numerous large branches. Pruning may therefore be equired to obtain the quality of desired products; however, one pruning rial in red alder (Berntsen 1961b) resulted in rot pockets and epicormic ranches.

The underutilized growing space at young stand ages may also lead to roblems with competition from unwanted volunteer vegetation. This would equire development of selective control methods. Existing harvest methods including cable yarding systems) are suitable. There should be fewer opographic restrictions for this option than for any other short-rotation ption for alder. Site preparation and control of competition, however, ould place additional restrictions on land suitable for this option.

Pulpwood Log and Sawlog Production

IELD ESTIMATES

Because of the potential problems associated with wide spacing, we ecided to examine a system that would yield both pulpwood logs and saw logs. he system involves rectangular spacing (8 by 16 feet) of the initial stand ith a row thinning for pulpwood at age 9 to 12. This would provide a quare spacing (16 by 16 feet) of leave trees for subsequent growth to saw-og specifications. Characteristics of the target stand at thinning and inal harvest dates are shown below:

Thinning (age 9 to 12)

Stems per acre- -	340
Spacing -	8 by 16 feet
D.b.h.- -	6 inches
Height- -	40 to 43 feet
Average tree volume (CVTS) - - - - - - - - - - - -	5.0 to 5.4 ft^3
Volume removed (CVTS) - - - - - - - - - - - - - - -	840 to 910 ft^3
Residual volume (CVTS)- - - - - - - - - - - - - - -	840 to 910 ft^3

Final Harvest (age 27 to 35)

Stems per acre- - - - - - - - - - - - - - - - - - - -	170
Spacing -	16 by 16 feet
D.b.h.- -	12 inches
Height- -	77 to 90 feet
Average tree volume (CVTS) - - - - - - - - - - - -	25.7 to 29.9 ft^3
Volume removed (CVTS) - - - - - - - - - - - - - - -	4,400 to 5,100 ft^3
Total yield (CVTS) thinning + harvest - - - - -	5,200 to 6,000 ft^3

Height at rotation age differs by site class. Length of rotation and mean annual production are listed for each site class in table 6.

Table 6--*Rotation age, time of thinning, and mean annual increment for the pulpwood log and saw-log option, by site index*

Site index	Rotation age	Thinning	Mean annual increment[1/]		
			4-inch top	Total stem	Total tree
Feet	- - -Years- - -		Cubic feet per acre per year		
90	35	12	140	150	210
100	32	11	160	170	240
110	29	10	180	200	280
120	27	9	200	220	310

[1/] Thinning plus final harvest.

Total production by this system would be about 6 percent less than tha of the saw-log and peeler option, and rotation age is estimated to be 3 yea less. Gains of 40 percent over normal yields would occur. Again, utiliza- tion of tops and branches would increase total yield to 210 to 310 cubic feet per acre per year.

SPECIAL CONSIDERATIONS

The objectives of the 8- by 16-foot initial spacing with thinning are several. The denser spacing should result in fairly decent stem form and possibly in more rapid natural pruning. Thus, some of the problems antici- pated with wider spacings may be lessened or avoided. In addition, early pulpwood production and thinning permits capture of site productivity normally lost with wide spacing and an earlier return on investment. Becau of increased competition at young ages, expected rotations are 3 to 5 years longer than needed to produce trees of 12-inch d.b.h. with an initial stock ing of 170 trees per acre.

Warrack (1964) indicated that epicormic branching occurred in a 37-yea old alder stand in British Columbia after thinning, but he does not mentior the problem in his discussion of thinning a 21-year-old stand. Neither doe Berntsen (1958, 1961a, 1962) mention epicormic branching of alder stands

nned at 8 and 21 years of age. Perhaps epicormic branching is not a rious problem when young, vigorous stands are thinned as suggested in this ion.

Site requirements are identical to those for the pulpwood log option. ntations should be oriented to avoid cross-slope yarding which would likely r and degrade some leave trees. The lean or sweep that is characteristic alder in unmanaged, irregularly spaced stands may result from phototropic sitivity of the species (Warrack 1956). If this is true, the geometric cing of plantations may minimize this problem.

Site preparation needs would be similar to those mentioned for the pwood log option. Control of natural vegetation after planting, however, more likely to be necessary because of the wider spacing.

A Wrap-Up

At present there is little interest in intentional management of red ler by most major forest product companies and public landowners. This k of interest stems from the fact that merchantable volumes are lower logging costs are higher in alder stands than in conifer stands. More-r, past market values for alder logs have been lower and much more table than for conifer logs. Some of these factors can be affected by agement and developments in harvesting technology. Market values will be ected by future changes in supply and demand for raw materials in fiber solid wood products industries. If future changes increase the attrac-eness of alder management, foresters have a wide range of options available. the four options presented in this paper, we suspect that the pulpwood log the pulpwood log and saw-log options will receive more attention than coppice and the saw-log and peeler options because potential problems fewer and the need for new technology is less. In addition, these two h forest options afford greater flexibilities to foresters and mill agers in growing, harvesting, and utilizing the wood produced than does coppice system. The period between initial cost outlay and first re-ns on investment is considerably shorter for the two pulpwood log options n for the saw-log and peeler option.

Experimental yields for the coppice system are high and in combination h waste disposal benefits, may lead to establishment of such plantations r mills. Estimated yields for the high forest options are substantially her than those listed in the normal yield table for unmanaged stands at suggested rotation ages (see table 7). The higher yields as well as shorter time to harvest will enhance the profitability and therefore the ractiveness of alder management. Predicted yields of stands managed for id wood products are about 40 percent greater than those of natural nds of the same age, whereas relative gains for stands managed only for pwood are greater yet. We suspect that these increased yields are some-t conservative. They are based only on anticipated gains from proper cing. Given other intensive cultural treatments such as site prepa-ion, fertilization, and genetic improvement, even greater yields would ely occur.

Table 7--*Comparisons of short-rotation options and normal-yield table predictions in terms of yield at a given age and rotation age needed to attain a specified diameter*

Comparison[1/]	Yield (CVTS) at rotation age[2/]	Rotation age for specified diameter
	Cubic feet per acre	Years
Pulpwood log option	3,100	13
Normal yield table	1,100	22
Saw-log and peeler option	5,500	34
Normal yield table	4,100	47
Pulpwood log and saw-log option	5,500	32
Normal yield table	4,000	42

[1/] All data apply to site 100.

[2/] CVTS = cubic volume of total stem including stump and tip, inside bark. Normal yield table estimates were adjusted to total stem (inside bark) values based on conversion ratios presented in Brackett (1973).

In conclusion, it appears that intentional management of alder will result in much higher yields than occur naturally with this fast-growing species. If we consider alder's nitrogen-fixing ability, such yields increase the attractiveness of alternating a short rotation (e.g., 10 to 1 years) of alder with longer rotations of conifers, especially on the more nitrogen-deficient sites. As fiber and solid wood supplies become more costly to produce, alder seems destined to occupy a more prominent niche i the resource management picture of the Pacific Northwest.

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GROWTH AND YIELD OF RED ALDER: EFFECTS OF SPACING AND THINNING

J. HARRY G. SMITH, Professor
Faculty of Forestry
University of British Columbia
Vancouver, B.C.

ABSTRACT

In this paper I review information on the growth and yield of red alder. Recent point sample studies of 131 trees from Point Grey near Vancouver, British Columbia and 116 trees from the University of British Columbia Research Forest near Haney, B.C. are reported to show how trees and stands grow. Most attention is paid to the few studies which have demonstrated how growth of 20-year and older stands can be concentrated on fewer, higher quality stems.

Because very little is known about potential gains from spacing, planting, or precommercial thinning of red alder in the Pacific Northwest, I summarize data from current studies. Tree ring analyses of disks and cores are used to learn how surviving trees in old stands grew when young. I also discuss problems caused by multiple, missing, and locally absent rings. The critical period of stand establishment and heavy self-thinning is described using data from eight 0.1-acre plots in 8- to 10-year-old stands and from two 0.1-acre plots in 25-year-old stands. The basic units were 0.001-acre plots in which species and d.b.h. of all live and dead trees were recorded. Comparisons are made between several characteristics of mean trees on 0.001-acre plots and the biggest trees on 0.01 acres (top height trees). The 0.001-acre plots are regrouped into various plot sizes and configurations and stand densities measured by numbers of trees, d.b.h., and basal area to show what increases in d.b.h. and height might result from spacing and thinning. I summarize stand density indices and stocking as expressed by crown cover as well as discuss the roles of light-seeking and lean in self-thinning. I give examples of the numbers of years required to grow to breast height and patterns of growth in height and diameter by deciles above breast height and I compare recent annual height growth with growth of branches.

Premiums for size and quality for well-spaced stands are reviewed in comparison with gains in volume for very dense stands. I concluded that stand managers have many exciting options for improving growth and yield of red alder; but, in order to confirm conclusions drawn tentatively from examination of temporary plots, sustained studies of spacing and precommercial thinning are needed.

Introduction[1]

Results of early studies of growth, yield, and biomass have been re- ported fully (Smith 1968, 1972, 1974a, 1975; Smith and DeBell 1973, 1974) there is no need to describe them here. My studies have documented the ve large differences in growth of open, average, and dense stands for the sou coast of British Columbia. Chambers (1974) reported empirical yields for predominantly alder stands in western Washington. Biomass, net primary pr ductivity and energy flows have been summarized for our 8- to 10-year-old stands by N. Smith (1977).

This paper stresses some recent work on growth and yield, on stand fo mation by natural seeding, and on effects of various levels of stocking an density, following complete site preparation. It evaluates trends in numb of trees per acre with increasing age and stand height in order to illustr how total growth and yield can be shaped by various spacings. The few ava able data on spacing control and on thinning are summarized. Tree ring an yses and conventional stem analyses are used to determine how stand format on well-prepared sites compares with that on less completely disturbed sta

Methods

Because there were so many unanswered questions about effects of stoc ing and density on growth and yield and about the extent to which small pl can represent large plots (Smith 1975), main stress was placed last summer upon sampling of square milacre subplots on Point Grey near Vancouver, B.C Within the 8- to 10-year age class, four 1/10-acre plots were established fully stocked but open stands for comparison with adjacent dense stands on similar sites. One open and one dense 1/10-acre plot were established in the 25-year age class. Each milacre plot was studied as a unit and then combined with its neighbors in order to show the effects of eight sample sizes and configurations on estimates of yield. The areas sampled were naturally seeded following clearing for roads or housing projects. Site quality is medium, 35 feet at age 10 (Smith 1972). Most soils are sandy loams or loamy sands and well drained. Precipitation averages 45 inches annually. Stem analyses and tree-ring analyses were made to document heig growth patterns to age 10 and to compare stand formation on intensively pr pared land with that of older trees growing on less disturbed sites create by logging.

Bole shape and crown development are stressed. Numbers and basal are of live and recently dead trees are used to show effects of stand density on average and maximum yields. The effects of age can be seen by comparis

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d 25-year-old stands. Results are displayed in tables which can be answer or illustrate many important questions about growth and yield cts of spacing and thinning of red alder. Data from the young stand n be compared with the characteristics of trees measured during mpling on Point Grey and near Haney. Only the center trees were fully on Point Grey. Near Haney all trees in the point sample were (Smith 1974b).

RISTICS OF INDIVIDUAL TREES

t studies of growth and yield have reported volumes per acre with porting data on d.b.h., height, basal area, and numbers of trees but paid little attention to bole shape and crown development. e, the data in table 1 may be of particular interest because they iameters outside bark at root collar, 4.5, and 9 feet. In addition, e data on height to dead and live crowns, total height, crown width, ous ratios to show variation in lower bole shape and crown develop-

le 1 records data for trees in each of the 131 point samples made in red alder stands on Point Grey, on and near the University of Columbia campus. These can be compared with 116 red alders sampled oint sampling in 1973 (Smith 1974b) on the University of British Research Forest near Haney. The averages and data on variation in- he range of tree characteristics that can be expected up to 45 years and to 80 years on Point Grey. Stand densities as expressed by ea per acre are similar, 145 square feet. Stocking as expressed by ver averages 75 percent for both areas. There are 24 point samples to 10-year-old stands on Point Grey among the data in table 1. hich average 30 feet in length are about twice as deep as they are or both areas, the ratios of crown widths in feet to d.b.h. in inches risingly high, about 2.3 and like, the ratio of height to crown H/CW) seem to indicate open growth. On the other hand ratios of d.b.h. t indicate rather crowded stands. Lower boles of both groups have per.

ree of lean was measured as an indicator of the extent to which many ve grown toward light in canopy openings created by natural thinning. raged 6 degrees, and ranged from 0 to 30 degrees for the Point Grey Trees without lean should survive better and produce more valuable therefore be favored during spacing control

le 2 compares mean trees in milacre plots for 8- to 10- and 25-year- ds on Point Grey. Data are given on angle of lean in degrees. The data are summarized to show the d.b.h. of the maximum tree on each In addition, the quadrats are summarized by numbers of live and es and amounts of live and dead basal area. The ratios of maximum d.b.h. and of dead to live basal area on each milacre are shown.

data on averages and variation in tables 1 and 2 describe what we d may also help planning of similar studies in other areas.

Table 1--*Comparison of point sampled red alder from Point Grey and University of British Columbia Research Forest near Haney*

Variable[1/]	Point Grey (N=131)					Haney (N=116)				
	Average	S.D.	Min.	Max.	C.V.	Average	S.D.	Min.	Max.	C.V.
D.b.h.(D)	6.99	3.85	1.0	20.8	55.1	8.92	2.96	3.1	16.8	32.1
R.C.D.	8.68	4.82	1.2	25.0	55.3	10.4	3.34	3.6	19.2	32.2
9.F.D.	6.52	3.51	0.8	19.0	53.8	8.5	2.76	3.	16.1	33.4
Percent C.C.	74.2	12.5	50.0	95.0	16.8	75.1	19.3	30.	90.	25.7
C.W.	15.0	7.17	3.0	43.0	47.7	18.7	7.46	10.	35.	25.5
H.L.C.	35.4	13.3	6.0	63.0	37.6	21.8	8.79	6.	50.	40.4
H.	63.8	22.4	14.0	112.0	35.1	55.0	14.0	20.	98.	25.4
B.A.	146.3	49.2	40.	300.	33.7	144.8	37.2	60.	300.	25.7
L.C.L.	28.4	15.0	3.0	88.0	52.8	33.3	12.3	2.	73.0	36.8
L.C.L./H.	.439	.127	.083	.87	29.0	.598	.143	.1	.842	23.9
C.W./D.	2.37	.762	.779	5.0	32.1	2.21	.52	1.07	3.85	23.6
H./C.W.	4.61	1.44	1.88	12.3	31.3	3.04	.822	1.33	6.53	27.0
9.F.D./D.	.936	.066	.80	1.53	7.10	.955	.025	.863	1.00	2.66
D./R.C.D.	.81	.076	.538	.964	9.32	.861	.076	.544	.988	8.84
H./D.	10.3	2.89	4.62	20.9	27.9	6.5	1.6	.294	12.6	24.6
D./H.	.104	.029	.048	.217	27.8	.163	.042	.08	.34	25.7

[1/] Standard deviations (S.D.), minimum (min.), maximum (max.), coefficients of variation (C.V.), root collar (R.C.D.), 9-foot diameters (9.F.D.) in inches; crown cover (C.C.) in percent; crown width (C.W.), height to live crown (H.L.C.), total height (H.), and live crown length (L.C.L.) in feet; basal area (B.A.) per acre in square feet; and various crown and boles development ratios. Prisms with a basal area factor of 20 were used. On Point Grey only the center trees were measured fully; near Haney, all trees in the point sample were measured (Smith 1974a).

Table 2--*Comparison of mean trees on milacre plots of red alder from 8- to 10- and 25-year-old stands on Point Grey*[1/]

Variable[2/]	8-10 year plots (N=782)					25-year plots (N=93)				
	Average	S.D.	Min.	Max.	C.V.	Average	S.D.	Min.	Max.	C.V.
R.C.D.	2.17	.88	.70	6.20	40.6	8.31	2.26	3.90	14.3	27.2
D.b.h.	1.69	.69	.30	4.80	40.9	6.93	1.76	3.10	11.3	25.5
9.F.D.	1.53	.68	.10	4.40	44.0	6.57	1.72	2.80	11.2	26.2
H.D.C.	4.8	3.8	0	26.0	80.4	22.0	12.7	0	50.0	58.0
H.L.C.	13.3	6.5	1.0	36.0	48.9	40.2	13.0	10.0	66.0	32.3
C.W.	6.2	2.7	2.0	16.0	43.4	13.0	5.8	4.0	30.0	44.8
H.	26.0	7.5	8.0	46.0	28.7	63.3	10.7	8.0	76.0	16.9
Lean	7.3	7.1	0	45.0	97.6	3.8	4.6	0	20.0	122.
Max. D.b.h.	2.43	.80	.50	7.10	33.1	7.00	1.71	3.1	11.3	24.5
Dead N.t.	2.95	3.15	0	19.0	107.	.118	.357	0	2.0	301.
Dead B.A.	.006	.009	0	.101	144.	.009	.030	0	.177	348.
Live N.t.	7.08	5.43	1.0	33.0	76.7	1.16	.398	1.0	3.0	34.3
Live B.A.	.084	.048	.003	.321	57.2	.313	.169	.052	.917	54.2
Max. D./D.	1.54	.532	.94	5.25	34.5	1.02	.079	1.0	1.52	7.7
D.B.A./L.B.A.	.11	.315	0	6.94	285.	.041	.151	0	1.05	370.

[1/] Variables as in table 1 plus height to dead crown in feet (H.D.C.), amount of lean in degrees, and for each milacre plot maximum d.b.h., number of dead trees, dead basal area, number of live trees, and live basal area in square feet. The ratios are for maximum d.b.h. to mean d.b.h. and for dead basal area to live basal area.

[2/] Standard deviations (S.D.), minimum (min.), maximum (max.), coefficients of variation (C.V.), root collar (R.C.D.), 9-foot diameters (9.F.D.) in inches; crown cover (C.C.) in percent; crown width (C.W.), height to live crown (H.L.C.), total height (H.), and live crown length (L.C.L.) in feet; basal area (B.A.) per acre in square feet; and various crown and boles development ratios. Prisms with a basal area factor of 20 were used. On Point Grey only the center trees were measured fully; near Haney, all trees in the point sample were measured (Smith 1974a).

INFLUENCE OF STAND DENSITY ON MEAN TREE CHARACTERISTICS AND MAXIMUM D.B.H.

Table 3 records the milacres from 8- to 10- and 25-year-old stands in order of increasing stand density expressed as numbers of trees per milacr This is the best way to employ single examination plots to infer what migh have happened as a result of early control of stand density. As numbers o trees per acre increase from 1,000 to 25,000 and space per tree drops from 6.6 to about 1.4 feet, the size of mean trees decreases as shown. Mean tr sizes of 2.4- inch d.b.h. and 33.5-foot height drop to 1.0-inch d.b.h. and 20-foot height. Crown widths and lengths, and thus capacity for further growth, are much greater in the least dense plots. The numbers of dead trees increase with stand density but still average about two in the milac now supporting only one tree. Live basal area per acre increases from 36 square feet for 1,000 trees per acre to about 100 square feet per acre for stands having 5,000 or more trees per acre. At this age, 5,000 trees are needed to occupy each acre fully, in terms of basal area per acre.

On the 25-year milacres reported in table 3, the self-thinning process has been carried to the point when no milacre supports more than three living trees. Basal areas per acre on those milacres which still have tre are very high, 278 for 1,000 and 518 square feet for 2,000 trees per acre. The ratio of dead to live basal area decreases rapidly with increasing sta density.

Table 4 records some influences of plot size on mean trees per milacr and shows what thinning to favor trees with the largest d.b.h. could do to increase stand size. Because four plots were square, .004-, .009-, .016-, and .025-acre, it was not possible to use all milacres. The largest trees on each milacre were compared to determine their average size and associat mean tree characteristics as plot size was increased. If these stands wer entered now and thinned to favor trees with the largest d.b.h., d.b.h. of residual trees could be increased by 1.37 inches from 2.43 to 3.80 inches trees per acre were decreased from 1,000 to 40, in 8- to 10-year-old trees In the 25-year class the maximum d.b.h. could be increased by 2.51 inches from 7.00 to 9.51 inches. On the stocked quadrats, live basal area per ac increased from 84 to 139 square feet in the 8- to 10-year class and from 313 to 529 square feet in the 25-year age class.

One aspect of major interest is the very rapid accumulation of basal area per acre in the 8- to 10-year-old stands. These stands average 98 square feet per acre which compares very well with 152 at age 25 and 187 a age 75. There also are very real possibilities for increasing yield if ma agers could learn how to control stocking and density in order to achieve best values that have been observed on small plots.

INFLUENCE OF STAND DENSITY ON HEIGHT

The small increases in height of mean trees associated with the large trees on plot sizes up to .025 acres (40 trees per acre) in table 4, sugge that these largest trees are large because of factors in addition to site.

Table 3--*Influence of number of trees per milacre on characteristics of mean trees*[1/] *per milacre for 8- to 10- and 25-year-old stands*

Age class (years)	Number of plots	Root collar	D.b.h.	9-foot diameter	Height to dead crown	Height to live crown	Crown width	Height	Lean	Max. d.b.h.	$D_{max.}/D_{aver.}$	Basal area Dead/Live	Dead: Number of trees	Dead: Basal area	Live: Basal area	Live: Number of trees
		(in.)	(in.)	(in.)	(ft.)	(ft.)	(ft.)	(ft.)	(degrees)	(in.)				(sq. ft.)	(sq. ft.)	
8-10	43	3.04	2.37	2.21	5.1	18.5	9.4	33.5	9.4	2.37	1.00	0.525	1.93	.0117	.0359	1
	76	2.78	2.16	1.97	5.2	15.0	8.3	30.0	7.5	2.71	1.32	.155	1.60	.0070	.0662	2
	95	2.56	1.98	1.81	4.8	15.0	7.5	29.4	8.2	2.56	1.34	.136	2.07	.0074	.0696	3
	95	2.33	1.84	1.68	5.2	14.3	6.7	27.6	7.0	2.64	1.55	.094	2.00	.0064	.0837	4
	93	2.29	1.83	1.66	4.3	13.6	6.9	27.6	7.7	2.72	1.57	.077	2.64	.0071	.1022	5
	59	2.11	1.63	1.48	5.1	12.8	6.0	25.0	5.5	2.41	1.59	.097	2.99	.0065	.0813	6
	59	1.98	1.55	1.40	4.9	12.7	5.8	23.8	6.1	2.38	1.60	.048	2.29	.0048	.0851	7
	45	1.92	1.47	1.28	4.5	11.4	5.5	23.8	7.4	2.36	1.66	.073	3.00	.0067	.0920	8
	38	1.91	1.49	1.33	4.7	12.1	4.9	23.4	6.3	2.44	1.71	.048	2.63	.0048	.0975	9
	24	1.78	1.36	1.20	5.2	11.1	4.7	22.9	8.0	2.19	1.94	.062	3.08	.0058	.0960	10
	17	1.72	1.27	1.12	4.6	9.6	4.0	21.0	5.9	2.15	1.73	.045	2.47	.0036	.0904	11
	22	1.80	1.39	1.24	5.8	12.2	4.8	22.3	5.3	2.23	1.67	.052	3.77	.0053	.1015	12
	15	1.76	1.35	1.23	6.1	12.1	4.5	23.2	8.0	2.23	1.66	.037	3.40	.0041	.1123	13
	18	1.68	1.26	1.11	3.3	9.4	4.2	23.1	4.7	2.06	1.68	.044	4.67	.0046	.1147	14
	16	1.41	1.09	.97	4.0	9.7	3.8	20.9	10.3	1.93	1.83	.058	6.81	.0054	.0926	15
	18	1.36	1.06	.92	3.7	10.5	3.4	19.6	8.9	1.90	1.81	.060	6.33	.0049	.0912	16
	5	1.32	1.00	.86	5.4	11.2	4.0	19.4	6.0	1.66	1.71	.048	6.40	.0033	.0788	17
	4	1.42	1.10	.98	3.9	12.0	4.3	21.2	7.5	1.88	1.71	.061	5.75	.0036	.1006	19
	9	1.28	.99	.86	2.4	10.3	3.6	20.1	8.9	1.97	2.09	.068	10.00	.0075	.1009	20
	7	1.26	1.00	.90	4.1	11.0	3.6	19.7	7.9	1.73	1.74	.032	6.71	.0027	.0840	21
	6	1.38	1.10	.97	3.3	12.0	3.7	20.8	6.7	1.92	1.83	.062	8.00	.0078	.1118	25
25	79	8.32	6.93	6.56	21.9	40.5	12.9	62.8	3.2	6.93	1.00	.047	.13	.0099	.2783	1
	13	8.48	7.13	6.82	22.2	38.2	13.6	67.3	7.2	7.54	1.08	.008	.08	.0024	.5175	2

[1/] In addition to the variables recorded in table 2, number of milacres (number of plots) for each stand density (live number of trees) class are given. Multiplying N.t. by 1,000 gives trees per acre to show the effects of increasing stand density on mean tree characteristics.

Table 4--*Influence of plot size on mean trees from plots with largest d.b.h. in 8- to 10- and 25-year-old stands*[1]

Trees/acre Plot size, acre	1,000 .001	500 .002	250 .004	200 .005	111.1 .009	100 .010	62.5 .016	40 .[illegible]
Milacres	782	400	191	160	64	80	34	31
Variable:[2]	-Averages for 8- to 10-year-old trees-							
R.C.D.	2.17	2.32	2.42	2.47	2.63	2.45	2.45	2.[illegible]
D.b.h.	1.69	1.82	1.89	1.95	2.05	1.95	1.96	2.[illegible]
9 F.D.	1.53	1.65	1.72	1.78	1.87	1.76	1.78	1.[illegible]
H.D.C.	4.8	4.77	4.69	4.87	5.48	5.17	4.47	5.[illegible]
H.L.C.	13.3	13.7	14.1	14.4	14.5	14.6	13.5	15.[illegible]
C.W.	6.2	6.4	6.7	6.7	7.2	6.8	7.1	6.[illegible]
H.	26.0	27.0	27.4	27.5	27.9	27.3	27.2	27.[illegible]
Lean	7.3	6.7	6.4	6.6	6.0	6.7	7.6	7.[illegible]
Max. D.	2.43	2.77	3.12	3.21	3.48	3.50	3.75	3.[illegible]
Dead N.t.	2.95	2.70	2.69	2.51	2.67	2.33	2.35	2.[illegible]
Dead B.A.	.006	.0056	.0053	.0055	.0056	.0057	.0056	.[illegible]
Live N.t.	7.08	7.19	7.47	7.09	6.89	7.00	6.53	6.[illegible]
Live B.A.	.084	.0993	.1141	.1183	.1250	.1315	.1341	.[illegible]
Max. D./D.	1.54	1.67	1.83	1.83	1.98	2.00	2.07	2.[illegible]
D.N.T./L.N.T.	.417	.499	.471	.455	.526	.459	.402	.[illegible]
D.B.A./L.B.A.	.110	.067	.047	.045	.044	.042	.039	.[illegible]
Milacres	93	78	48	38	18	20	8	8
Variable:[2]	-Averages for 25-year-old trees-							
R.C.D.	8.31	8.47	9.35	9.57	10.62	10.6	11.40	11[illegible]
D.b.h.	6.93	7.08	7.80	7.93	8.73	8.71	9.24	9[illegible]
9 F.D.	6.57	6.71	7.40	7.51	8.37	8.28	8.85	9[illegible]
H.D.C.	22.0	22.1	24.1	21.7	23.2	24.7	21.6	16.[illegible]
H.L.C.	40.2	40.7	45.0	43.5	46.9	46.0	47.4	43[illegible]
C.W.	13.0	13.3	15.0	15.4	15.8	17.2	14.9	17[illegible]
H.	63.3	63.6	66.5	64.2	69.6	66.7	71.6	70.[illegible]
Lean	3.8	3.8	3.8	3.5	4.6	2.9	6.3	1[illegible]
Max. D.	7.00	7.17	7.90	8.02	8.86	8.71	9.54	9.[illegible]
Dead N.t.	.12	.13	.17	.21	.17	.05	.13	0
Dead B.A.	.009	.0097	.0012	.0147	.0127	.0028	.0022	0
Live N.t.	1.16	1.18	1.21	1.18	1.28	1.20	1.38	1.[illegible]
Live B.A.	.313	.329	.397	.407	.503	.483	.598	[illegible]
Max. D./D.	1.02	1.02	1.02	1.02	1.02	1.00	1.05	1.[illegible]
D.N.T./L.N.T.	.103	.122	.156	.197	.167	.050	.125	0
D.B.A./L.B.A.	.041	.044	.045	.053	.030	.011	.003	0

[1]The influence of thinning to leave the tree of largest d.b.h. for various plot sizes and associat[illegible] numbers of trees per acre can be seen by comparing average d.b.h. with maximum d.b.h. for each age class

[2]Root collar (R.C.D.), breast-high (D.b.h.) 9-foot diameters (9 F.D.) and maximum diameter (Max. D[illegible] in inches; crown width (C.W.), height to live crown (H.L.C.), total height (H.), and live crown length (L.C.L.) in feet; basal area (B.A.) per acre in square feet; and various crown and boles development ratios. Live or Dead N.t. refers to number of trees. Prisms with a basal area factor of 20 were used. On Point Grey only the center trees were measured fully; near Haney, all trees in the point sample were measured (Smith 1974a).

lthough their larger size may be due to minor effects of age and micro-ite, it is likely that some genetic advantages also exist.

The decrease of maximum d.b.h. with increasing stand density (table 3) hows that not even greatly increased opportunities for genetic and micro-ite selection can overcome the increased competition within very dense tands.

TAND FORMATION AND RECENT GROWTH

In order to determine how the stands grew initially in the eight plots stablished in 8- to 10-year-old stands, stem analyses were made of the big-est tree on 0.01-acre plots. Table 5 records data for these top height rees. Their 1976 d.b.h. and height are shown, plus average annual height rowth to breast height and for the years 1973 to 1976. Average and maximum umbers of trees and basal area per acre are shown for each plot. Mean an-ual increments of total cubic feet volumes per acre in all trees averaged 04 (52-172) in 8- to 10-year-old stands and 162 in 25-year-old stands. In eneral, the densest plots support the shortest mean trees, but there must lso be a site quality effect on height growth. Most trees which are slow o reach breast height will be associated later with below average height rowth.

Table 6 records the average annual growth for 1973-76 for two branches ut from the widest part of the crowns of top height trees. In 1973, branch rowth averaged 2.58 feet which was 78 percent of height growth. In 1976 ranch growth averaged 0.99 feet which was only 54 percent of height growth. hese data on slowing of branch growth and presence of few branches older han 4 years, confirm observations that because of their intolerance, lower ranches do not persist long in dense alder stands.

Table 7 records actual rather than extrapolated data (Smith 1972) on verage heights at ages 1 to 8 and estimates for 9 and 10 for the biggest rees on 0.01 acre plots. At age 10, heights of dominant and codominant rees should average 47 feet on good, 35 on medium, and 23 feet on poor ites (Smith 1972, table 18). Therefore, it can be seen that our plots racket the medium site class and provide new information on the shape of eight curves to age 10.

REE-RING ANALYSES OF DISKS AND CORES

Red alder is a diffuse-porous species with poorly defined rings. If reat care is taken during ring counts, it is possible to estimate annual rowth from cores and disks; but there will be considerable uncertainty. In ost years, radial growth stops with the formation of a dense band of fibers .03 to 0.30 mm wide. In some years such a band of fibers is formed on a ew trees, but then followed by another much smaller ring of apparent early-ood and another band of latewood at the end of the growing season. Some ears when crowns have been damaged, no ring will be formed at breast height, nd occasionally there will be locally absent rings at breast height.

Table 5--*D.b.h., height, and height growth of average top height trees on eight plots of 8- to 10-year-old trees, and numbers of trees and basal area per acre for average and maximum milacre plots*

Plot	1976		Average annual height growth, feet[1]					Number of trees per acre		Basal area per acre	
	D.b.h.	Height	To breast height	1973	1974	1975	1976	Average	Maximum	Average	Maximum
1	4.17	37.8	5.00	3.98	4.35	3.91	2.33	2,557	7,000	81	268
2	2.47	22.1	2.37	2.93	2.75	1.93	1.53	4,755	12,000	44	117
3	3.75	37.5	4.09	4.18	4.99	3.36	1.77	3,456	9,000	66	177
4	2.30	26.9	2.81	3.26	3.52	2.46	1.76	17,149	37,000	82	164
5	3.15	27.1	3.46	2.93	2.48	1.54	0.90	8,380	19,000	79	192
6	4.45	36.7	4.50	2.86	3.01	2.31	1.43	3,705	13,000	104	321
9	3.56	31.4	3.75	3.00	3.25	2.41	2.11	7,041	16,000	81	201
10	3.80	33.0	4.50	3.20	3.10	1.97	2.80	6,383	19,000	93	229

[1] Averages for all top trees (heights of trees of largest d.b.h. on 0.01 acres) on each plot. The 1976 data were collected in late June or early July, values for other years are based upon stem analyses.

Table 6--*Recent growth of the widest branches of top height trees*

Plot	1973		1974		1975		1976	
	Branch number 1	2	Branch number 1	2	Branch number 1	2	Branch number 1	2
	- - - - - - -	Average annual branch growth, feet	- - - - - - -					
1	3.50	3.70	4.43	3.05	3.93	3.57	1.83	1.87
2	2.81	2.67	2.56	2.49	3.23	2.99	.65	.54
3	2.54	2.40	2.96	3.19	3.27	2.75	1.00	1.01
4	2.47	2.56	2.55	2.45	2.00	1.91	.74	.94
5	1.98	1.99	2.25	1.78	1.72	1.77	.51	.47
6	2.31	2.52	2.08	2.31	1.94	1.85	.59	.79
9	2.25	2.58	2.34	2.44	1.91	1.85	1.26	1.32
10	2.47	2.60	2.03	2.33	1.93	1.70	1.20	1.13

Table 7--*Height growth of the biggest trees on 0.01-acre plots in 8- to 10-year-old stands*

Growth	Age class (year)									
	1	2	3	4	5	6	7	8	9	10
	- - - - -Average heights of 10 top height trees (feet)- - - - -									
Slow	3.0	6.0	10.0	13.7	16.0	19.0	21.0	24.5	26.0	28.3
Average	2.3	6.0	10.6	15.5	19.7	23.7	27.3	29.2	32.0	34.3
Fast	2.0	6.0	11.5	19.0	24.5	27.0	31.5	35.0	38.5	42.0

ecial care must be taken to measure typical rings and to date stand origin mith 1974a).

Table 8 records average growth of the top height trees by plots for the rst 8 or 9 years from pith. These data based upon careful measurements of sks show the buildup of growth from around 0.1 inch in the 1st year to peak at ound 0.3 or 0.4 in the 5th or 6th year with a decrease to 0.1 or 0.2 inches the 8th or 9th year. Probably the recent decrease in radial growth is sociated with the high density of these plots, which was illustrated in ble 5. With wider spacing, the high growth rate could be sustained much nger.

Table 9 is based upon measurements of cores made by a Swedish tree ring asuring instrument (Addo-X). Two cores were extracted at breast height om each of the 131 Point Grey samples in table 1. Widths of earlywood and tewood were measured and processed by conventional methods (Smith, Cown, d Parker 1976). In addition, specific gravity of each core was determined d a subsample of 10 cores processed by x-ray densitometry (Parker, Smith, d Johnson 1977). Measurements of the first cores taken from each tree re subsequently reanalyzed for the four areas in table 9 to illustrate e widths of latewood, earlywood, and rings as well as percentage latewood. eas 1 and 4 support latewood about twice as thick as that found on areas and 3, perhaps because more water is available late in the season. All eas have very low percentages of latewood, and there is very little dif- rence in specific gravity between latewood and earlywood components of ngs. In order to compare the average levels and patterns of table 9 with ose in table 8, it is convenient to remember that 4 mm equals .157 inches d 6 mm equals .236 inches. Then it can be seen that table 9 does not pear to have equivalents for the first two rings from pith that were meas- ed for table 8. Because not all cores hit the pith, table 9 probably erestimates widths of the first few rings from pith. Apart from this, ere is little in table 9 to suggest that the mean trees in the point mples are much different in juvenile growth from the top height trees from ich the disks were taken in very dense plots. Thus, we have indirect ev- ence of rather similar patterns of stand development in young and old ands. Unpublished measurements of recent annual growth when compared with e data recorded in table 9 shows that in 25-year-old stands percentage tewood doubles and ring width halves. Even when ring widths drop to av- age 1.5 mm in 75-year-old stands, percentage latewood seldom exceeds 8.

Table 8--*Radial growth at 0 and 4.5 feet for top height trees on 8- to 10-year-old plots*

Plot	Section[1/]	Age (year)	Ring from pith									Number of disks
			1	2	3	4	5	6	7	8	9	
			Radial growth (in)									
All	R.C.	9.16	0.09	0.15	0.28	0.22	0.30	0.31	0.26	0.21	0.19	73
	B.H.	7.89	.09	.13	.25	.20	.27	.27	.25	.19	.15	73
1	R.C.	8.70	.05	.12	.33	.34	.40	.46	.42	.36	.15	10
	B.H.	7.80	.05	.12	.30	.30	.38	.39	.38	.14	--	10
2	R.C.	8.70	.16	.12	.28	.31	.30	.26	.15	.05	.06	10
	B.H.	6.80	.10	.13	.28	.27	.24	.18	.06	--	--	10
3	R.C.	9.00	.10	.22	.36	.23	.33	.35	.30	.22	.14	10
	B.H.	7.90	.09	.18	.27	.21	.29	.31	.27	.16	--	10
4	R.C.	8.60	.08	.13	.20	.12	.23	.20	.17	.13	.07	10
	B.H.	7.00	.08	.12	.20	.12	.22	.19	.15	.10	--	10
5	R.C.	9.20	.06	.12	.22	.17	.30	.31	.26	.20	.17	10
	B.H.	7.90	.06	.10	.19	.16	.25	.29	.23	.15	--	10
6	R.C.	10.00	.10	.15	.29	.20	.28	.32	.29	.32	.37	10
	B.H.	9.00	.09	.15	.25	.19	.25	.30	.29	.29	.21	10
9	R.C.	9.70	.13	.15	.27	.19	.29	.27	.23	.20	.24	10
	B.H.	8.50	.14	.14	.26	.18	.27	.25	.20	.16	.10	10
10	R.C.	10.00	.19	.21	.27	.18	.26	.27	.17	.21	.24	3
	B.H.	9.00	.15	.16	.23	.17	.24	.22	.20	.23	.11	3

1/ Disks were cut at root collar (R.C.) and breast height (B.H.).

Table 9--*Widths of latewood (L) (.01 mm), earlywood (E), rings (R) and percentage latewood (% L/R) for the first 10 rings from pith for four areas on Point Grey*

Area	Number of trees	Variable	Rings from pith at breast height									
			1	2	3	4	5	6	7	8	9	10
1	34	L	14	16	17	15	15	14	13	16	15	15
		E	627	604	546	478	432	426	342	375	424	385
		R	641	620	563	492	447	440	356	391	438	400
		L/R	2.5	4.2	3.4	3.8	4.4	3.7	5.8	5.2	4.7	5.3
2	16	L	7	9	8	9	7	8	7	8	9	10
		E	749	688	742	629	615	554	431	492	429	362
		R	755	697	750	638	622	562	438	500	438	372
		L/R	1.2	3.0	1.5	1.9	1.5	1.4	2.4	1.9	3.3	3.4
3	33	L	6	6	7	7	6	8	6	7	7	6
		E	559	545	559	518	585	554	454	537	454	435
		R	565	552	566	526	591	562	460	544	461	442
		L/R	1.6	3.3	3.3	3.5	2.9	2.1	2.3	1.7	2.6	2.6
4	11	L	17	17	14	18	14	13	16	11	14	12
		E	729	729	802	569	610	550	474	468	453	476
		R	746	746	816	586	624	563	489	479	466	488
		L/R	2.6	3.5	2.1	3.9	2.8	3.0	3.8	5.1	3.4	4.5

VARIABLE DENSITY ESTIMATES OF YIELD

Table 10 illustrates the effect of stand density expressed in terms of relative basal area upon average d.b.h. and numbers of trees per acre. These data were obtained by point sampling during the 1966 inventory of Crown Zellerbach's Tree Farm License No. 2. Following calculation of average basal area per acre in trees 3.1-inch d.b.h. and larger, point samples were classified to illustrate the effects of five stand density classes. The classes were 1-50 percent for open, 51-80 for sparse, 81-120 for average, 121-150 for dense, and more than 150 percent of average basal area per acre for very dense stands. As can be seen best for the 35-year age class in each site class in table 10, the low basal areas of open stands may result from stocking with few, usually large trees. High basal areas come from survival of many, usually small trees. The relatively few large trees of open stands of red alder probably are the result of incomplete stocking that allowed trees to grow at open growth rates (Smith 1972, 1974a). The very dense stands probably represent full occupation of the site with crowded trees that will suffer heavy mortality as self-thinning reduces their number in the immediate future.

If there are good premiums for size, the timber manager should aim for average or dense stands at age 35. If the objective is to maximize yield at harvest and size is not important, the timber manager should grow stands which become very dense at the desired harvest size (Smith 1976, 1977).

The average yields expected by the B.C. Forest Service for good, medium and poor site classes are shown for 7.1-inch and larger trees in table 11. It appears as if mixture of conifers with alder leads to increased yield. The Crown Zellerbach data from table 10 do not represent the same site classes because the top two are roughly equivalent to the B.C. Forest Service good site, but yields of 70- and 90-year age classes exceed those indicated by the B.C. Forest Service volume-over-age curves.

SELF-THINNING

The natural role of self-thinning is obvious to anyone who has observed the growth of alder seedlings as I did this spring. I started out with 346 million seedlings per acre at 1-inch height and these decreased to 25 million seedlings per acre at 6 inches. The inevitable decrease of numbers of trees with increased height or d.b.h. is subject to much variation, which I can illustrate for our 875 milacres in 9- and 25-year-old stands. The logarithm of number of trees per milacre can be estimated from the logarithm of mean d.b.h. to account for 47.2 percent of the variation with an error of estimate of .276. Using only the 151 plots with 12 or more live trees at age 8-10 or 2 to 3 live trees at age 25 leads to a statistically superior equation with R^2 0.823 and standard error of estimate of .119. Unfortunately, the intercepts and regression coefficients are nearly identical to those for the full sample so the statistical gain is illusory. Use of height with mean d.b.h. did not improve the equations. For the 131 point samples summarized in table 1, the logarithm of average d.b.h. accounted for 68.0 percent of the variation in logarithm of number of trees per acre. Estimation with the logarithm of height accounted for 49.3 percent of the

Table 10--*Average d.b.h. (D) and numbers of trees per acre (Nt) by stand density classes*[1/] *for pure and mixed red alder, 3.1 inches + d.b.h*

Age class	All		Open stands		Sparse		Average		Dense		Very dense		All	All
	D.b.h.	Number of trees	D.b.h.	Number of trees	D.b.h.	Number of trees	D.b.h.	Number of trees	D.b.h.	Number of trees	D.b.h.	Number of trees	Basal area	Number of point samples
	Site class 2 (170 at 100) (135 feet at 50 years)													
25	10.2	389	7.8	251	13.8	155	11.2	292	--	--	10.3	692	220	6
35	12.0	277	18.8	38	11.9	199	11.7	276	12.0	311	10.0	654	178	44
45	11.9	323	--	--	9.6	326	12.6	3.09	12.4	375	--	--	232	13
55	13.8	272	--	--	14.3	186	13.4	266	13.9	368	--	--	251	11
65	15.3	182	19.0	42	--	--	15.0	182	13.8	254	--	--	189	11
														(85)
	Site class 3 (140 at 100) (95 feet at 50 years)													
15	6.8	489	--	--	4.5	670	8.3	310	6.3	578	--	--	97	5
25	9.6	386	--	--	10.3	227	9.0	405	9.8	655	9.1	591	153	25
35	10.7	312	12.1	107	11.2	193	10.2	352	11.7	319	9.7	587	166	80
45	12.1	299	13.8	88	12.1	175	13.2	224	10.2	487	10.7	712	190	31
55	13.8	304	18.3	88	16.7	121	12.6	347	13.1	399	--	--	246	25
65	13.0	231	10.0	147	14.5	138	12.8	234	11.7	352	14.0	297	179	24
85	18.3	138	19.3	59	18.5	86	17.9	150	--	--	18.2	244	248	5
														(195)
	Site class 4 (110 at 100) (75 feet at 50 years)													
25	9.8	255	8.0	143	8.9	163	15.4	108	8.2	431	--	--	116	5
35	9.4	302	8.7	146	8.8	255	10.4	243	8.8	447	9.6	466	131	21
45	9.0	535	--	--	--	--	8.8	548	10.6	459	9.9	602	220	7
55	12.5	281	18.0	45	10.2	215	15.5	137	12.7	308	--	--	196	11
65	10.2	392	--	--	--	--	10.2	392	--	--	--	--	220	2
														(46)

[1/] Open (O) stands have 1-50 percent, sparse (S) have 51-80 percent, average (A) 81 120, dense (D) 121-150, and very dense (VD) 151+ percent of the average basal area per acre in square feet tabulated on the righthand side of the table along with number of point samples.

Table 11--*Some average yields by site and age class*

Site class	Age class	Alder plus conifer[1]		Alder plus deciduous[1]		Alder plus conifers or hardwoods[2]
		Number of plots	Cubic foot volume 7.1 in+	Number of plots	Cubic foot volume 7.1 in+	Cubic foot volume 3.1 in+
1	30	2	5,829	5	3,773	6,204
	50	2	5,037	5	4,440	7,125
	70	2	6,134	1	5,455	9,946
		6		11		
2	10			3	950	
	30	14	4,334	25	3,126	3,825
	50	13	4,963	26	4,242	5,638
	70	6	4,618	7	3,382	8,539
	90	9	6,290	5	4,117	11,752
		42		66		
3	10	2	720	9	2,188	2,944
	30	12	3,039	15	2,046	4,336
	50	4	3,932	3	4,531	6,551
	70	2	2,998	3	3,145	--
	90	1	6,609	--	--	--
		21		30		

[1] B.C. Forest Service estimates for the south coast of B.C. for total cubic foot volume (Vcu) between a 1-foot stump and a 4-inch top d.i.b., less decay only, in trees 7.1 inches and larger in d.b.h., for good, medium, and poor sites.

[2] Crown Zellerbach averages for the data reported in table 10.

variation. Although the natural role of self-thinning will be difficult t define precisely from observations of temporary sample plots, it is feasib to extrapolate using either d.b.h. or height to estimate numbers of trees per acre. With further study, more useful stand density indices (Reineke 1933) probably could be developed; but best results will come from analyse of spacing trials (Smith 1976).

EARLY CONTROL OF SPACING

Apart from the Cascade Head Provenance trial in which red alder from localities were planted as 1-foot-tall seedlings at 5- x 10-foot spacings and thinned to 10 x 10 feet in 1976 (Clapp 1977), I have no data on contro of spacing by planting. In 1975 Northwest Hardwoods planted 100 acres of red alder as 18- to 24-inch tall seedlings at 300 trees per acre near Port Angeles. In 1977 Walters is establishing two Nelder spacing trials for re alder on the University of British Columbia Research Forest. Similar studies should be established throughout the Northwest.

The only data I can find on early thinning of a young stand to create regular spacings were provided by Northwest Hardwoods in 1973. In April 1962 on the Pilchuck Tree Farm a 7-year-old alder stand was thinned to provide three 0.1-acre plots at 8-, 12-, and 16-foot spacings. When remeasure after 12 growing seasons in 1973 at age 19, a control plot was established. Early control of spacing had effectively redistributed growth. In comparis

ih the unthinned natural stand which supported 660 trees and 114 square et of basal area in 5.4-inch average d.b.h. stems, the 8 x 8 plot had 590 es, 108 square feet, and 5.9-inch average d.b.h.; the 12 x 12 plot had trees, 77 square feet, and 7.2-inch average d.b.h.; and the 16 x 16 plot 180 trees, 43 square feet, and 8.1-inch average d.b.h. The increase of .h. by 2.7 inches in 12 years was associated with a reduction of 71 are feet in basal area per acre. At this time the best spacing appears be 12 x 12 but this could be increased if growth of the widely spaced es continues to improve. With alder pulpwood selling at only $20.00 per d at the mill, conversion of trees to more valuable products by spacing trol and thinning can be very important, financially.

Near Northwest Bay on the east side of Vancouver Island, poor results lowed an operational spacing at age 16, when the stand contained 1,266 es per acre averaging 4.35 inches in d.b.h. and 42 feet in height, to per acre. The thinning had no influence on d.b.h. or height by age 23 n both control and thinned areas supported trees 6.6 inches in d.b.h. 57.5 feet tall (Smith 1974a). Four years later the situation had not roved. In one 0.05-acre plot in the control, the 14 biggest trees aver- d 6.8 inches in d.b.h., and were larger than the 14 trees in the spaced t which averaged only 6.3 inches. The 33 trees in the control plot av- ged 4.6 inches in d.b.h. Affleck[2] concluded:

> Spacing does not release growth, but in fact, reduces eventual merchantable volume. Twenty-eight percent of the spaced trees developed heavy epicormic branching, while there was no evidence of epicormic branching in the control stand. There was no evidence of better growth form in the spaced stand compared to the control stand. Two trees were wind thrown in the spaced stand, while no trees were wind thrown in the control stand. The site itself is a good alder site.

FECTS OF THINNING

A major objective of thinning is the redistribution of gross volume owth onto the best trees in a stand. Results of thinning studies avail- le to 1973 (Smith 1974a) showed that timing of thinning was very important d response uncertain. Warrack (1964) reported that thinning could increase erage d.b.h. by about 4 inches but reduced the absolute yield greatly. ch an increase in size could have great importance in situations where the andard of utilization is rough. It might convert a loss of $125.26 per M m for 10-inch d.b.h. trees to a breakeven of $0.94 for 12-inch trees or a modest profit of $16.58 per M fbm for 14-inch trees (Tessier and Smith 61).

[2] Peter Affleck, MacMillan Bloedel Industries, Northwest Bay, B.C.

Conclusions

My analyses of these data should be refined and enhanced by simulation methods, but these could not substitute fully for field trials. Long-term research is needed to determine the extent to which stands can be shaped toward desired goals by planting and by early control of spacing. The data presented for various stand densities have illustrated substantial potential for thinning to improve tree size. It is possible that planting or very early control of spacing in natural stands could increase both harvest size and yields by concentrating growth on the best trees for 20 to 30 years.

If a maximum of biomass or of full tree volumes is desired, a uniform distribution of closely spaced seedlings should be developed for harvest at age 10 to 15 years before excessive self-thinning reduces mean annual yields.

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INSECT PESTS OF RED ALDER: POTENTIAL PROBLEMS

R. I. GARA, Professor of Forest Entomology
College of Forest Resources
University of Washington
Seattle, Washington

L. L. JAECK, Graduate Student
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

Although insect problems of red alder receive little attention at present, concern about insect damage will increase with increasing value and management of the species. Tent caterpillars and sawflies appear to offer the most serious threats to intensive management; defoliation by these insects could lead to drastic reductions in growth of heavily infested stands. Chrysomelid beetles, such as the alder flea beetle, can also be destructive as both larval and adult stages defoliate alder. Bark beetle populations are normally low and damage is limited; however, increased harvest, if accompanied by large amounts of logging slash, could result in population build-up and subsequent attack and mortality of trees in residual stands. Ambrosia beetles attack down logs and can degrade lumber unless removal and utilization proceeds promptly after felling.

Introduction

As the value of red alder (*Alnus rubra* Bong.) increases, the level of t damage tolerated decreases. Undoubtedly the time will come when red er's present insect complex will assume greater importance and effective trol practices will be in demand.

In recent times, *A. rubra* is gradually shifting from an undesirable cies to one of increasing utility; and studies on silvical characterics have begun (*20*, *21*); however, there is little current research on ect pests, especially on the potential impact of pest problems. Availe entomological information is in the form of short pest descriptions *6*, *7*, *8*, *10*), reports of outbreaks (*3*, *5*), and as initial studies into biology and control of potentially important pests (*2*, *13*, *14*, *15*, *16*, . This paper will highlight some of the available literature and stress entially serious problems.

Tent Caterpillars

There are two important lepidopteran defoliators of red alder, the forest tent caterpillar (FTC), *Malacosoma disstria* Hbn., and the western tent caterpillar (WTC), *M. californicum* (Packard). The FTC could become most destructive pest threat to the intensive management of western hardwoods. The insect is common on a multitude of hardwood species throughou most of continental North America; severe and widespread outbreaks are common (*1*). In British Columbia, a 1948 to 1954 outbreak spread from num ous dispersed foci into a general infestation that covered thousands of acres (*5*). Outbreaks in Eastern North America have occurred every 6-16 years (*9*); Condrashoff (*5*) reports that population fluctuations are extre

Defoliation by the FTC and subsequent height and diameter reductions aspen and birch are will documented. Growth losses as high as 86 percent during a time of especially severe defoliation have been noted, although tree mortality is negligible (*11*).

It is suggested that applied control of FTC outbreaks can be effecte through use of a nuclear-polyhedral virus (*12*, *16*). Oliver (*14*) found t aerial applications of Bidrin® at 0.25 lb/acre and phosphamidon at 1.0 lb/acre was an effective FTC control in Louisiana.

Red alder also is a highly preferred host for *M. californicum*, and 8-year outbreak cycles have been suggested in the Pacific Northwest (*18*). Worthington et al. (*21*) found that WTC outbreaks reduce tree growth over 2-year period; tree mortality, however, is rare.

The WTC has a number of natural control agents. In British Columbia a combination of parasites, nuclear-polyhedrosis and other viruses, patho genic fungi, bacteria, and microsporidia have been effective to the poin that WTC is not considered to be a serious pest in that province (*13*).

Bacillus thuringiensis Berliner, a crystalliferous spore-forming bacterium, has shown promise as an effective pathogen in field tests (*13*) Third instars were highly susceptible to thuricide 90TS foliar sprays. I addition to inducing larvae mortality immediately, the bacterial agent ha sufficient residual life to prevent *M. californicum* reinfestation for up a year.

Wellington (*18*) noted that a tachinid fly parasite, *Tachinomyia simi* (Williston), was especially effective in laying its eggs on the larvae of during prolonged hot weather.

Alder Flea Beetle

The alder flea beetle, *Altica ambiens* (Lec.), belongs to a large fam of leaf eating beetles, the Chrysomelidae. These insects can be especial destructive as both larval and adult stages defoliate alder. Other than

ts general life cycle (*19, 10*), little is known about *A. ambiens*. Oviposi-ion begins in the spring on partially rolled leaves, the emerging larvae nd subsequent instars are voracious feeders. Leaves on saplings and pole-ized trees can be completely skeletonized in about a month. Shortly there-fter new adults emerge, and they feed on remaining leaves.

Pyrrhalta punctipennis (Mann.), another small chrysomelid, is also an ctive defoliator of red alder in the Pacific Northwest. Practically noth-ng is known about *P. punctipennis*; in fact, general texts omit the fact hat it feeds on alder. Turnbull (*17*), however, has observed the damage aused by this beetle; he reports that red alders around Burnaby, BC, ave been seriously damaged by *P. punctipennis*.

Sawflies

The red-backed sawfly, *Eriocampa ovata* L., introduced into North America rom Europe (*3*), is a leaf skeletonizer of *Alnus*. This pest has seriously efoliated alder stands in eastern Canada and heavy damage recently has been eported in British Columbia (*3*). The insect has two generations per year n the Northwest and, under favorable environmental conditions, it is likely hat outbreaks could develop, especially since *E. ovata* may have few biological ontrol agents. Turnbull (*17*) considers that the red-backed sawfly may evelop into the greatest insect pest of *A. rubra* in the Northwest. He also uggests that the sawfly is becoming more prevalent in response to the in-reased amount of available red alder.

The striped alder sawfly, *Hemichroa crocea* (Fourcroy), is another little-nown defoliator of red alder. This insect also was introduced from Europe, nd Craighead (*6*) mentions that red alder defoliations have been reported in ritish Columbia. *H. crocea* has two generations per year. It is conceiv-ble that in combination with *E. ovata*, extensive sawfly damage could be xpected.

Bark and Ambrosia Beetles

The alder bark beetle *Alniphagus aspericollis* (Lec.) breeds in the hloem of alder slash and young stressed trees. Its biology is well known *7, 2*). As with most economically important bark beetles, *A. aspericollis* an become a threat to healthy red alder stands. The alder bark beetle opulation is normally low with colonization limited to scattered down logs nd the occasional weakened tree. If the harvest of red alder were, however, o increase dramatically, with a great deal of logging slash left in the oods, bark beetles will find and attack this material. Shortly thereafter, he beetle population would increase (especially as they have two generations er year); and if the population were large enough, residual stands also ould be attacked. Moreover, light *A. aspericollis* infestations result in solated patch kills on the stems of attacked trees; these kills can provide n area for entrance of subsequent wood rotting fungi (*2*).

Tent Caterpillars

There are two important lepidopteran defoliators of red alder, the forest tent caterpillar (FTC), *Malacosoma disstria* Hbn., and the western tent caterpillar (WTC), *M. californicum* (Packard). The FTC could become th most destructive pest threat to the intensive management of western hardwoods. The insect is common on a multitude of hardwood species throughout most of continental North America; severe and widespread outbreaks are common (*1*). In British Columbia, a 1948 to 1954 outbreak spread from numer ous dispersed foci into a general infestation that covered thousands of acres (*5*). Outbreaks in Eastern North America have occurred every 6-16 years (*9*); Condrashoff (*5*) reports that population fluctuations are extreme

Defoliation by the FTC and subsequent height and diameter reductions o aspen and birch are will documented. Growth losses as high as 86 percent during a time of especially severe defoliation have been noted, although tree mortality is negligible (*11*).

It is suggested that applied control of FTC outbreaks can be effected through use of a nuclear-polyhedral virus (*12, 16*). Oliver (*14*) found tha aerial applications of Bidrin® at 0.25 lb/acre and phosphamidon at 1.0 lb/acre was an effective FTC control in Louisiana.

Red alder also is a highly preferred host for *M. californicum*, and 8-year outbreak cycles have been suggested in the Pacific Northwest (*18*). Worthington et al. (*21*) found that WTC outbreaks reduce tree growth over a 2-year period; tree mortality, however, is rare.

The WTC has a number of natural control agents. In British Columbia, a combination of parasites, nuclear-polyhedrosis and other viruses, pathogenic fungi, bacteria, and microsporidia have been effective to the point that WTC is not considered to be a serious pest in that province (*13*).

Bacillus thuringiensis Berliner, a crystalliferous spore-forming bacterium, has shown promise as an effective pathogen in field tests (*13*). Third instars were highly susceptible to thuricide 90TS foliar sprays. In addition to inducing larvae mortality immediately, the bacterial agent had sufficient residual life to prevent *M. californicum* reinfestation for up to a year.

Wellington (*18*) noted that a tachinid fly parasite, *Tachinomyia simili* (Williston), was especially effective in laying its eggs on the larvae of WT during prolonged hot weather.

Alder Flea Beetle

The alder flea beetle, *Altica ambiens* (Lec.), belongs to a large famil of leaf eating beetles, the Chrysomelidae. These insects can be especially destructive as both larval and adult stages defoliate alder. Other than

its general life cycle (*19, 10*), little is known about *A. ambiens*. Oviposition begins in the spring on partially rolled leaves, the emerging larvae and subsequent instars are voracious feeders. Leaves on saplings and pole-sized trees can be completely skeletonized in about a month. Shortly thereafter new adults emerge, and they feed on remaining leaves.

Pyrrhalta punctipennis (Mann.), another small chrysomelid, is also an active defoliator of red alder in the Pacific Northwest. Practically nothing is known about *P. punctipennis*; in fact, general texts omit the fact that it feeds on alder. Turnbull (*17*), however, has observed the damage caused by this beetle; he reports that red alders around Burnaby, BC, have been seriously damaged by *P. punctipennis*.

Sawflies

The red-backed sawfly, *Eriocampa ovata* L., introduced into North America from Europe (*3*), is a leaf skeletonizer of *Alnus*. This pest has seriously defoliated alder stands in eastern Canada and heavy damage recently has been reported in British Columbia (*3*). The insect has two generations per year in the Northwest and, under favorable environmental conditions, it is likely that outbreaks could develop, especially since *E. ovata* may have few biological control agents. Turnbull (*17*) considers that the red-backed sawfly may develop into the greatest insect pest of *A. rubra* in the Northwest. He also suggests that the sawfly is becoming more prevalent in response to the increased amount of available red alder.

The striped alder sawfly, *Hemichroa crocea* (Fourcroy), is another little-known defoliator of red alder. This insect also was introduced from Europe, and Craighead (*6*) mentions that red alder defoliations have been reported in British Columbia. *H. crocea* has two generations per year. It is conceivable that in combination with *E. ovata*, extensive sawfly damage could be expected.

Bark and Ambrosia Beetles

The alder bark beetle *Alniphagus aspericollis* (Lec.) breeds in the phloem of alder slash and young stressed trees. Its biology is well known (*7, 2*). As with most economically important bark beetles, *A. aspericollis* can become a threat to healthy red alder stands. The alder bark beetle population is normally low with colonization limited to scattered down logs and the occasional weakened tree. If the harvest of red alder were, however, to increase dramatically, with a great deal of logging slash left in the woods, bark beetles will find and attack this material. Shortly thereafter, the beetle population would increase (especially as they have two generations per year); and if the population were large enough, residual stands also could be attacked. Moreover, light *A. aspericollis* infestations result in isolated patch kills on the stems of attacked trees; these kills can provide an area for entrance of subsequent wood rotting fungi (*2*).

Down logs and slash are attacked heavily by three ambrosia beetle species, *Gnathotrichus almi* Blkm., *Trypodendron lineatum* (Olivier), and *Xyleborus saxeseni* (Ratzeburg). These beetles bore into the sapwood of logs and degrade the lumber by their entry holes, egg cradles, and accompanying stain. Prompt removal of logs from the forest, and subsequent utilization will prevent this type of damage.

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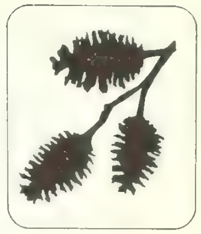
RED ALDER MANAGEMENT AND DISEASES



CHARLES H. DRIVER, Professor of Forest Resources
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

Relatively little is specifically known about diseases of red alder with respect to management. The status of reports in the literature concerning the subject is outlined. Research remains to be conducted on the part played by diseases of this species in respect to management.

Many workers have observed that alder stands start exhibiting symptoms of decadence about age 40 (*3*). It is not evident from literature that such decadence is induced entirely by disease. At this early stage in our knowledge, this doesn't prove anything. In fact, I tend to think that forest pathologists have had little more than a mycological interest in this subject.

From this point of view, Shaw (*1*) reports 167 species of fungi have been collected in the Northwest on this host species. On perusing the literature I have found the following infectious diseases known to occur on red alder:

1. one canker disease (wood exposed by a parting of the bark tissue),
2. one flower disease (catkin broom),
3. two leaf spot diseases,
4. two powdery mildew diseases, and
5. one white trunk rot disease.

At this stage of our knowledge the trunk rot disease induced by *Fomes igniarius* is of major concern. The impact of this disease is loss of utility of most wood within 8 feet of a fruiting body on the merchantable portion of the main stem.

So much for our known bases of disease information. In the future we should classify the remainder of the 167 fungi known to occur on this host species and prepare an evaluation with respect to the interest in intensively culturing red alder. As demonstrated for many forest tree species, the more we manage a species the more protection problems we can expect.

An initial area of interest should be to determine the course of top die-back in stands reaching 40 years of age. It is unusual that the most active part of a tree just stops functioning without some logical explanation other than old age.

Hypoxylon fuscum is well known to occur on many betulaceous species, one of which is red alder; it is known to induce a white-type rot in a relatively short period following infection. The infection period and site has been observed to be in close association with living or recently dead tissue of limbs and the main stem of this host. To my knowledge, however, this potential pathogen has not been demonstrated to be the cause of top die-back of red alder. More work needs to be done on this problem.

It is interesting to note that attempts to infect this host with the well known root pathogen *Poria weirii* has failed (*2*). Several other root decay fungi have, however, been reported on the host. The most interesting of which was *Fomes annosus* (*1*), the well known pathogen of conifer species.

In addition to living tree diseases, life of wood in use is also of interest. If concern is not given to this subject, potential markets may not be long lived after development. Red alder is recognized within the trade to be short lived when used in close association with moist soil. Such misuse should be avoided. Even better, specific recommendations should be made for deep penetration treatment with a proven wood preservative prior to installation in decay hazard environments.

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THE ROLE OF RED ALDER IN REDUCING LOSSES FROM LAMINATED ROOT ROT

E. E. NELSON, Supervisory Research Plant Pathologist
Forestry Sciences Laboratory
Pacific Northwest Forest and Range Experiment Station
Corvallis, Oregon

E. M. HANSEN, Associate Professor
Botany Department
Oregon State University
Corvallis, Oregon

C. Y. LI, Soil Microbiologist
Forestry Sciences Laboratory
Pacific Northwest Forest and Range Experiment Station
Corvallis, Oregon

J. M. TRAPPE, Supervisory Research Plant Pathologist
Forestry Sciences Laboratory
Pacific Northwest Forest and Range Experiment Station
Corvallis, Oregon

ABSTRACT

*Red alder, in mixture with conifer or preceding stands of conifers, may be useful in reducing damage from laminated root rot (*Phellinus weirii*) on infested sites. This benefit could result from changes in soil nitrate, pH, fatty acids, phenolic compounds and microbial populations brought about by alder, as well as physical separation of susceptible root systems in mixed stands. Survey data tend to support this hypothesis. Disease incidence may be limited by reducing saprophytic survival of the pathogen or inhibiting its spread along conifer roots. Evidence for the former is greater than for the latter. Long-term experimental plots have been established to provide more definitive answers.*

Red alder is an unusual western forest tree species--not only as a hardwood with commercially valuable growth and form but, through a symbiotic relationship, it fixes atmospheric dinitrogen. Like other hardwoods, it is not damaged by *Phellinus* (*Poria*) *weirii*, cause of laminated root rot. It has also been hypothesized to function as a natural biological control of laminated root rot. In this paper, we critically evaluate present evidence regarding alder as a root rot control.

Importance of Laminated Root Rot

Laminated root rot is the most damaging disease of young-growth Douglas-fir in the Northwest. The annual loss is estimated at 32 million cubic feet in western Oregon and Washington (*2*). This includes the volume of trees killed by the fungus as well as the additional volume of timber that could have grown on root rot sites in the absence of the disease.

BIOLOGY OF THE PATHOGEN

Phellinus weirii is characterized by its slow spread, long survival time, and wide host range. These attributes lead to formation of slowly expanding infection pockets with long-dead trees in the center, a fringe of recently killed trees, and infected but still living trees around the perimeter. *Phellinus weirii* spreads along live roots from tree to tree increasing the radius of infection centers by about 1 foot a year (*17*). Spread is relentless but often erratic, governed by the pattern of susceptible root contacts beneath the stand. When live roots are not present, e.g. after harvest or a fire, the fungus can wait where it is for roots of the new generation to grow in contact with the old infected ones. The fung remains viable in most infected stumps for 20 years and then slowly dies ou (*6*). All western conifers are attacked, but pines and Cupressaceae tolerat the infection. Douglas-fir, the true firs, mountain hemlock, and in some situations western hemlock are very susceptible.

Laminated root rot is not evenly distributed through the Douglas-fir region; but where found, it often limits production of Douglas-fir. We suspect that intensive Douglas-fir management aggravates the problem. In natural forests, *P. weirii* must occur in a balanced state, slowly expanding around the perimeter of infection centers but dying out at its center in brush-filled openings as stands age. Root rotted trees often fall over, pulling much of the infective, rotted roots from the ground. A managed forest, on the other hand, is characterized by short generation times, stum with infected roots left in the ground, and eradication or reduction of brush which might otherwise temporarily replace susceptible conifers.

CONTROL OPTIONS

No quick and easy control options are available to the forester. Fungicides don't reach the fungus below ground and fumigation is slow and costly. Physical removal of infected stumps greatly reduces residual inoculum but is feasible only on gentle slopes and with small stumps. The only real options for many managers are to accept the inevitable losses or to grow a less susceptible tree species. Of the *Phellinus*-tolerant conifer only western red-cedar is suitable for most of the westside Douglas-fir region, and we don't know how to establish and manage this species. This brings us back to red alder.

The resistance of red alder to infection by *P. weirii* is possible due in part to its phenolic and lipid content. The combination of phenolic compounds found in roots of red alder inhibits *in vitro* growth of *P. weirii*

(*13, 19*). Linoleic acid, an unsaturated 18-carbon fatty acid isolated from alder, also inhibits *P. weirii* (*12*).

Effects of Red Alder on Soil

The dinitrogen fixation by nodules on alder roots leads to substantial nitrogen accretion in the soil. Most of the fixed nitrogen is transferred from the nodules to the host tree and is then cycled to the soil by rain throughfall, litterfall, and death of roots and nodules. The most striking net result over time is a buildup of NO_3^- ions in soil under alder as compared to conifers (*1*).

The higher NO_3^- levels under alder may be important in limiting activity of *P. weirii*. It cannot utilize NO_3^- as a nitrogen source for lack of the enzyme nitrate reductase (*10*), but many of its potential microbial competitors in the soil can. Fertilization with either NO_3^- or NH_4^+ has been shown to reduce survival of *P. weirii* in soil (*15*). Alder has the advantage over fertilization of adding nitrogen to the soil each year and maintaining relatively high levels after initial buildup.

A number of phenolic compounds and fatty acids have been shown to inhibit *P. weirii in vitro* (*9, 18, 19*). Alder roots and litter contain twice as high a concentration of phenolics as do those of Douglas-fir (*13*). Shrubs common to many red alder stands, such as *Rubus spectabilis* and *Sambucus racemosa*, also produce *P. weirii*-inhibiting phenolics (*7*). The soil under alder reflects this combined production in having far higher levels of phenolics than soil under Douglas-fir although these levels are not high enough to inhibit *P. weirii in vitro*.[1] Total fatty acids of soils under alder do not vary appreciably from those under Douglas-fir, but the kinds of fatty acids do differ markedly between the two kinds of stands (*8*). Most fatty acids are probably not found in quantities which inhibit *P. weirii*. For example, the absolute amount of linoleic acid in alder soil is 100 times lower than the amount necessary for inhibition *in vitro*. Inhibition in soil, however, where nutrients are less available to the fungus, probably occurs at concentrations below those effective *in vitro*.

Soil under alder is considerably more acid than under conifer stands on similar sites (*1, 16*). Growth of *P. weirii* is reduced in an acid medium (*11*). This difference in environment could have indirect effects on the activity of *P. weirii* as well since competing microorganisms would also be effected.

The net effects of increased organism inhibitors of *P. weirii* associated with alder soils are virtually impossible to separate from those of nitrogen, pH, and activity of microbial antagonists. The chemistry and biological activity of such compounds may be synergistic. The compounds themselves are subject to transformation by soil organisms. In any event,

[1]Li, C. Y. Unpublished data, Pacific Northwest Forest and Range Experiment Station.

the increased amounts of such inhibitors under alder will not likely benefit *P. weirii*.

The comparative soil microbiology of conifer and alder stands, has be studied only at the Cascade Head Experimental Forest on the central Oregon coast. As might be expected in view of their chemical differences, alder soils differ substantially in microbial populations and activities. Most notably, the alder soils contain higher populations than conifer soils of some organisms with strong potential for antagonism against *P. weirii*. *Trichoderma viride*, a demonstrated antagonist against *P. weirii*, was characteristic of the alder soil but rare under conifers (*21*). Alder and conifer soils differed in populations of several other microfungi, but the antagonism against *P. weirii* remains to be assessed.

Mechanisms for Disease Control

The hypothesis that alder somehow reduces incidence of *P. weirii* infection developed from scattered observations in the field. Laboratory findings have tended to support it. Red alder could reduce disease incidence in three ways: (1) by reducing survival of *P. weirii* in stumps and roots following logging, (2) by occupying the site in place of susceptible conifers until the pathogen has died out, or (3) by inhibiting spread of the fungus along living roots. The first two suggests control through crop rotation; the third through mixed stands.

REDUCING SURVIVAL OF PATHOGEN

Nelson (*14*) buried wood cubes colonized by *P. weirii* in soil under 40-year-old stands of alder, mixed alder and conifers, and conifers (mainly Douglas-fir) on the Cascade Head Experimental Forest. Three plots were located in each of the three stands and 18 cubes were buried on each plot to a depth of 9 inches with minimal soil disturbance. Three cubes were removed after 3 months and after 6 months to test for survival of the fungus. Six cubes were removed similarly after 12 and 18 months. *P. weirii* survived in some cubes buried in "conifer" soil through 18 months, in "mixed" soil only through 12 months, and in "alder" soil only through 6 months.

The results were encouraging but the design of the experiment was relatively insensitive for detecting differences. As a followup, Nelson (*16*) established 12 pairs of plots on the Cascade Head Experimental Forest. This time, 12 cubes containing viable *P. weirii* were buried on each plot of a pair in soil supporting pure alder or pure conifer stands. Cubes were buried 8 inches (20 cm) with minimal soil disturbance. After 12 months, soil samples were taken at the depth of the cubes and all cubes were then removed. Although the fungus survived somewhat better under conifer than alder stands, (24 vs 22 per cent) the difference was not significant at the 95-percent level of confidence. Soil samples showed a significantly higher level of NO_3 and lower pH under alder stands. Either of these factors could affect disease development without affecting survival of the fungus in stumps and decaying root systems.

Beginning in 1974, Hansen (*6*) excavated *P. weirii*-infested Douglas-fir umps left 20, 30, and 50 years after logging. Initially, he looked at old umps in young Douglas-fir stands and found that with age the fungus had ed in many stumps. Where it hadn't, it was no longer viable at the tremities of roots.

Presently, infested Douglas-fir stumps in stands of young alder are ing examined to determine if *P. weirii* remains infective there for a orter time than in young Douglas-fir stands. A summary of data is shown table 1.

Table 1--*Survival of* Phellinus weirii *in old stumps and roots on sites now occupied by Douglas-fir or red alder*

mp e	Current stand	Stumps examined	Stumps with live *P. weirii*		Roots with live *P. weirii*	Average root diameter at limit of live *P. weirii*
rs		- -Number- -		Percent	Number	cm
	fir	69	65	94	--	12.5
	fir	65	38	58	87	18.9
	fir	24	6	25	6	23.7
	alder	45	33	73	102	11.0

In work completed, the fungus survived in 21 percent (94 vs 73 percent) ewer stumps under alder than it did under fir after 20 years. *P. weirii* emained viable, however, in somewhat smaller roots than it did in stands f Douglas-fir.

In British Columbia, Wallis (*20*) found viable *P. weirii* in old-growth tump roots as small as 4-cm diameter in 40-year-old mixed alder-Douglas-fir tands. But he also observed that in inoculum used to infect roots artifiially, the fungus survived better in Douglas-fir stands than in mixed tands.

Alder seems to have some effect on *P. weirii* survival, but that effect s not dramatic and apparently requires a long time. How it happens, we ave already hypothesized. How consistently it happens, what factors nfluence its effectiveness, and how long it takes, we have yet to learn.

NHIBITING SPREAD OF PATHOGEN

Let's look at the second possibility of alder reducing disease incience. Microbiological and chemical changes in soil under alder have lready been suggested. It is reasonable to expect them to inhibit develop-

ment of some organisms such as *P. weirii*. Even if alder-induced changes ar not of the magnitude to significantly inhibit root disease, the physical presence of a non-host species acting as a spacer between host species should reduce spread dependent upon root to root contact.

What would happen if young mixed stands of alder and Douglas-fir refor ested infested sites? Hansen (*5*) examined four such stands on the Siuslaw National Forest in the Oregon Coast Ranges. Systematically selected healt and diseased Douglas-fir were sampled in stands ranging from 10 to 17 year old. In each case, it was determined whether or not an alder was present within 5 feet of the tree or within a distance equal to the height of the Douglas-fir being sampled.

Overall proximity to alder did not seem to affect chance of infection judging from either measure. Infections in young stands are initiated by contact with old, infested stump roots. The failure of alder in even-age mixture with Douglas-fir to prevent these initial infections is not surpri ing, considering the extreme infection hazard and short time for soil modification.

In 1972, Trappe and Wortendyke[2] examined Douglas-fir and adjacent mix alder-Douglas-fir stands which met certain criteria:

1. *Phellinus weirii* was endemic in the area.
2. Stand age was between 30 and 100 years and was similar for each stand of a pair.
3. Conifers in the mixed stand were not dominated by the alder.
4. Sites for each stand of a pair were similar. Extensive scouting produced only six pairs of stands meeting these criteria, all in southwestern Washington.

Transects 8-ft (2.4-meters)-wide were run through each paired stand. The length of the transects ranged from 600 to 2,600 ft (183-792 meters) depending on the limits of the stand but were the same for each stand of a pair. All standing trees within each transect (1,300 in all) were examined for signs of *P. weirii* infection.

Data shown in table 2 were analyzed by Wilcoxon's signed rank test (*3*) This is a nonparametric test: it neither assumes a normal distribution of the measure variable nor uses quantified data. With only six paired stand the test indicated no significant difference in *P. weirii* incidence betwee pure Douglas-fir and mixed alder-Douglas-fir transects. If we assume equal variance and normal distribution (without evidence this is so) and use percentage of infection in a Student's t test, we find that the chance of a

[2]Unpublished Survey Data, Pacific Northwest Forest and Range Experiment Station.

reater percentage of conifers being infected in pure stands than in mixed s significant (P<5 percent). Even if the assumption were valid, the sample sed was limited geographically. What occurs in southwestern Washington may ot occur throughout the range of red alder.

Table 2--*Laminated root rot in pure conifer stands vs. alder-conifer mixtures*

Pair no.	Trees with infection		Phellinus centers	
	Pure conifers	Alder-conifer mixtures	Pure conifers	Alder-conifer mixtures
	- - -Percent- - -		- - -Number- - -	
1	9.3	2.3	6	2
2	2.6	3.1	2	2
3	5.3	1.7	4	1
4	1.4	0.0	1	0
5	12.5	0.0	6	0
6	1.4	0.0	1	0
Average	5.41	1.18	3.3	0.8

Wallis (*20*) inoculated roots of Douglas-fir in pure and mixed alder-Douglas-fir stands in British Columbia. In addition to reduced survival of *P. weirii* in the inoculum that he used in mixed stands, he achieved only one-third the percentage of successful infections in mixed stands than in pure Douglas-fir stands. In other instances, however, *P. weirii* infections of Douglas-fir roots in 40-year-old mixed stands did not appear to be inhibited.

Thus the case for alder reducing disease incidence by inhibiting infection and spread on conifer root systems is equivocal. Until more evidence is examined, mixed stands cannot be recommended as a solution to *P. weirii* problems.

Research Needs

Many questions remain about the role of alder in root rot control, but the over-riding need is to determine if it is effective under field conditions. Much could be learned from old root rot centers that regenerated to alder and have since been reconverted to fir. But apart from being nearly impossible to find, such existing situations lack the documented disease histories necessary for quantifying changes in disease incidence. Long-term experimental plantings on documented disease sites seem to be the only way to satisfactorily test alder's capabilities. Existing stands are being used to answer the more limited question "How long does *P. weirii* survive in old infected stumps on sites regenerated to alder?" This project will be completed in 1977.

A series of long-term experimental plantings have been established to test the effectiveness of alder alone and in mixtures with Douglas-fir or hemlock as a means of reducing subsequent root rot losses (table 3). Each test was established and replicated on carefully documented root rot centers. They represent a major, long-term commitment to test alder as a biological control agent.

In the meantime, forest managers must depend upon established guidelines based upon our present knowledge of laminated root rot (*4*, *20*).

Table 3--*Established, long-term plots evaluating alder as a control agent for laminated root rot*

Study	Duration	Location	Landowner	Other cooperators
Effect of alder-hemlock mixed stand on incidence of laminated root rot	1974-2014	Mapleton, Oregon	Mapleton R.D. Siuslaw N.F. USFS	Pacific Northwest Forest & Range Exp. Station
Effect of alder-Douglas-fir mixed stands on incidence of laminated root rot	1975-2035	Shelton, Washington	Port Blakely Mill Company	Pacific Northwest Forest & Range Exp. Stn., Oregon State University
Effect of crop rotation with alder or cottonwood in disease incidence in succeeding stands	1975-2035	Rainier, Oregon	International Paper Co.	Pacific Northwest F & Range Exp. Stn., Oregon State Univ., Longview Fibre, Cro Zellerbach

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THE EFFECTS OF RED ALDER ON GROWTH OF DOUGLAS-FIR

RICHARD E. MILLER, Principal Soil Scientist
Pacific Northwest Forest and Range Experiment Station
USDA Forest Service
Olympia, Washington

MARSHALL D. MURRAY, Silviculturist
Western Forestry Research Center
Weyerhaeuser Company
Centralia, Washington

ABSTRACT

We describe the long-term effects of off-site red alder that were interplanted in 1933 within a 4-year-old Douglas-fir plantation in southwestern Washington. Insufficient available nitrogen limits tree growth in this plantation. Red alder clearly increased height and diameter of the associated dominant Douglas-fir. Improved growth in diameter began when the Douglas-fir emerged through the alder canopy. This emergence occurred at about 30 years from seed at Wind River and in several even-aged, mixed stands that we also investigated. By age 48, Douglas-fir volume per acre in the mixed stand averaged about 3,100 cubic feet compared to 2,900 cubic feet in the pure stand. Red alder volume was about 2,500 cubic feet. Maintaining red alder in Douglas-fir stands can increase merchantable yields on nitrogen-deficient sites. Controlling stand density at an early age is necessary to maintain both Douglas-fir and alder in a dominant or codominant position. To provide adequate nitrogen and not seriously reduce Douglas-fir growing stock, about 20 to 40 uniformly distributed red alder per acre should be retained.

Introduction

Red alder, the most widely distributed commercial hardwood in the Pa-
fic Northwest, supports nitrogen-fixing bacteria within nodules on its
ots. Alder or other nitrogen-fixing plants can improve site productivity
d growth of associated conifers by adding nitrogen and organic matter to
e soil. For these reasons, Tarrant and Trappe (*12*) suggested using red
der in a soil-improving rotation or as an admixture with other tree species.

Red alder is well suited for short rotations because of its rapid juve-
le growth and its ability to fix nitrogen at an early age; even 1-year-old
der have nodules and presumably nitrogen-fixing capacity. The rapid juve-
le growth of red alder is, however, a concern of foresters who want to

maintain adequate stocking of Douglas-fir in mixed stands; red alder's juvenile height growth is more rapid than the initially slower growing conifers'. For example, 10-year-old alder seedlings are 30 to 40 feet tall on average and good sites in Oregon (7). Without chemical or mechanical control, equal-aged alder usually overtops associated Douglas-fir for about the first 25 years (*14, 2*). A large proportion of the Douglas-fir usually die during this period of suppression. Newton et al. (7) concluded from their survey of young stands in western Oregon that successful Douglas-fir regeneration required an age advantage of 4 to 9 years or spacing so that the Douglas-fir were 8 to 10 years old before alder encroachment.

In this paper, we shall describe the long-term positive and negative effects of red alder that were interplanted in a young Douglas-fir plantation on the Wind River Experimental Forest in southwestern Washington. We shall then briefly summarize our findings in mixed stands at three other locations. In contrast to the Wind River study area, the alder in these stands originated from natural seeding and were equal in age to the associated Douglas-fir. Because there were no pure Douglas-fir stands at these locations, we could not compare growth of this species mixed with alder to its growth when not mixed with alder. Having read this paper, you should recognize the potential benefits and requirements of managing mixed stands of these species.

Methods

STUDY AREAS

Wind River

Site description.--This Site IV study area is located near Carson, Washington at approximately 2,000 feet elevation. The Wind River study area, on the east edge of the 294,000-acre Yacolt Burn, was swept by wildfire in 1902 and 1927. Annual precipitation averages 96 inches with 26 percent falling during the April through October period (*8*). The soil, a moderately deep, well-drained gravelly loam derived from pyroclastic rocks, contains approximately 3,000 pounds of total nitrogen per acre to a 3-foot depth (*1*[illegible]). This amount is about average for low productivity lands in western Washington. Insufficient available nitrogen limits growth of Douglas-fir in the study area as demonstrated nearby in the same plantation. A single application of 140 pounds of nitrogen per acre when the Douglas-fir were 35 years old increased volume growth by approximately 70 percent (600 cubic feet per acre) during the next 11 years.[1]

Stand description.--The plantation was established after the Yacolt Fire of 1927. Two-year-old Douglas-fir from an unknown, off-site seed source were planted on an 8- by 8-foot spacing after the 1928 growing season. Four years later, 2-year-old red alder seedlings were interplanted on a 6-

[1]Unpublished data on file at the Forestry Sciences Laboratory, Olympia, Washington. See also (*6*).

y 6-foot spacing to create a 70-foot wide strip as a firebreak. These alder ere also off-site, because the seed was collected at a 50-foot elevation ear Olympia, Washington but the seedlings planted at a 1,900 to 2,100-oot elevation.

Early observers recorded that nearly all these off-site alder seedlings ere severely frosted during the first fall and spring after planting, yet he native alders growing in the same locality were not frosted. The inter-lanted red alder would probably have competed more severely with the ouglas-fir if the alder seed had been collected at a similar or higher levation as the planting site. Therefore, the results from the Wind River tudy may not be typical of natural Douglas-fir/red alder stands. We will espond to this concern later in this paper.

Despite off-site seed sources and delayed planting, however, the Wind iver study area has advantages for determining the effects of red alder on rowth of Douglas-fir. First, one can validly compare growth of fir with nd without alder influence, because the Douglas-fir plantation was uniform n origin and spacing and the alder was restricted to one strip through the ouglas-fir plantation. In contrast, the so-called "pure" fir stand at our ascade Head study area was created from a mixed stand by removing the alder fter it had influenced the Douglas-fir for at least 8 years *(1)*. Second, nsuffieient available nitrogen seriously limits growth of the Douglas-fir at he Wind River study area. Therefore, this species should respond to nitro-gen additions by red alder.

Cascade Head, Delezenne, Skykomish

To check the general applicability of our findings at Wind River, we xamined data from even-aged, mixed stands at three other locations in the acific Northwest.

Site characteristics.--Site index of the coastal Oregon stand at Cascade ead was somewhat higher than that at Wind River location (table 1). The elezenne and Skykomish installations are both Site I based on trees with inimal influence of red alder.

Table 1--*Site characteristics of the even-aged stands*

Stand	Location (near)	Elevation	Annual precipitation	Soil	Site index (50-year)
		Feet	Inches		
Cascade Head	Lincoln City, OR	600	90	silty clay loam	120
Delezenne Creek	Elma, WA	200	70	silt loam	136
Skykomish River	Sultan, WA	400	50	silt loam	146

Stand description.--The Douglas-fir and red alder in these three areas originated from natural seeding with the exception of the Douglas-fir at Skykomish which were machine-planted. The oldest stand, at Delezenne Creek was established after logging and burning; the other two succeeded abandoned pastures (table 2).

Table 2--*Stand descriptions of the even-aged stands*

Stand	Succession after	Total age at measurement	
		First	Last
		- - - -Years- - - -	
Cascade Head	pasturing	9	41
Delezenne Creek	logging and burning	30	53
Skykomish River	pasturing and logging	20	20

MEASUREMENTS

Wind River

Field.--When the Douglas-fir were 48 years from seed, we established four 0.2-acre plots in the pure stand and four matching plots in the mixed stand. These plots sampled a slope gradient from a level ridge to near a small creek. After measureing d.b.h. of all trees 1.6 inches and larger to the nearest 0.1 inch, we measured heights of 15 trees per plot of each species present. Randomization was constrained in that two-thirds of these trees exceeded the mean d.b.h. of the species on the plot and our height sample included the tree of largest d.b.h. for each plot and species. To determine breast-high age and past trends of diameter growth, we bored the eight largest trees of our height sample from each plot.

During plot installation, we noted that a large proportion of the trees in both the pure and mixed plantation had deformed boles. We assessed this past crown damage by estimating the height to the lowest point of bole deformity and classifying its effect on stem form and volume above this damage point.

Office.--We used standard procedures for summarizing data collected in the field. We computed 50-year site index for the six Douglas-fir that represented the upper 20 percent of the d.b.h. range on each plot (*4*). Cubic volumes of sample trees were based on general volume tables for Douglas-fir[2] and for red alder (*3*). The volume equation for each species and plot had the following format: Cubic volume, total stem = a + bD + cD^2, where D = diameter at breast height.

[2]James E. King and Kenneth J. Turnbull. Total tree cubic-foot volume table for Douglas-fir. Unpublished report. Copy on file at Forestry Research Center, Weyerhaeuser Company, Centralia, Washington.

Cascade Head, Delezenne, and Skykomish

We used data from seven mixed stands to compare with our Wind River data:

Stand	Plots Quantity	Plots Size
	(Number)	(Acres)
Cascade Head[3]	2	0.5
Delezenne Creek[4]	4	.2
Skyhomish River	1	.08

We computed site index (*4*), and examined trends in tree numbers by species, and height-diameter relations for these plots.

Results and Discussion

WIND RIVER

We shall first contrast the 48-year-old Douglas-fir in the mixed stand with the same seed source in the pure stand. We'll also show the tree size and volume attained by the alder in the mixed stand. In addition, we shall reconstruct past trends in number of trees and in height-diameter relations as indicators of past competition within the mixed stand. Finally, we'll compare the incidence and severity of past bole damage in both stands.

Current Stand

Dominant heights.--In the mixed stand at Wind River, red alder clearly increased height growth of associated dominant Douglas-fir. In four pairs of plots, heights of eight dominant Douglas-fir per plot averaged 14 to 27 percent taller in the mixed stand than those in the pure stand. Site index of these 48-year-old Douglas-fir stand was increased by 13 to 26 feet (table 3).

Site index of Douglas-fir in the pure stand was lowest at the top of the slope and gradually increased toward the creek (table 3). Site index in the mixed stand showed the same trends. The apparent gain in site index from the alder influence was least near the creek, presumably because soil nitrogen and moisture status were least improved by alder's additions of nitrogen and organic matter.

[3]Data provided by Richard E. Carkin, Forester, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, in January 1977.

[4]Data provided by James E. King, Department Manager, Resource Evaluation, Weyerhaeuser Western Forestry Research Center, Centralia, Washington, in February 1977.

Table 3--*Average dominant height and site index of 48-year-old Douglas-fir at Wind River*

Stand	Slope position of sample plot				
	Upper	Middle		Lower	Mean
	- - - - -Dominant height - feet- - - - - -				
Mixed	71	87	86	89	84
Pure	56	65	73	78	68
Difference	15	22	13	11	16
	- - -Site index, 50-year base - feet- - - -				
Mixed	92	106	111	110	105
Pure	69	80	92	97	84
Difference	23	26	19	13	21

Recall that red alder was planted in the mixed stand when the Douglas-fir were 6 years from seed. Height of dominant Douglas-fir in the mixed stand began exceeding that of dominants in the pure stand shortly after the red alder was introduced (fig. 1). The difference in average height of the 40 largest Douglas-fir per acre increased over time and was statistically significant ($P<0.01$) for ages 18 through 48 years.

Total stand volume.--Douglas-fir volume per acre in the mixed stand (fig. 2) averaged about 3,100 cubic feet compared to 2,900 cubic feet in the pure stand (fig. 3). This apparent 7-percent gain in cubic volume by age 48 however, was not statistically significant. Red alder volume averaged 2,500 cubic feet per acre. Therefore, the combined volume of both species was nearly twice the volume of the pure stand.

Tree numbers and volumes by diameter classes.--To compare stumpage values and logging costs in the mixed and pure stands, one needs to consider numbers and volumes of trees in specified diameter classes. We'll first compare Douglas-fir in the pure versus the mixed stand, then show size and number of red alder that were 4 years younger.

About one-half of the nearly 400 Douglas-fir per acre in the pure stand were in the 6-inch diameter class (table 4). This broad class included trees that were 5, 6, and 7 inches in diameter at breast height. Such trees could be merchantable in pulpwood under intensive utilization. In the 12-inch and larger classes, there were 22 trees per acre. These trees could be merchantable as sawtimber under current utilization standards.

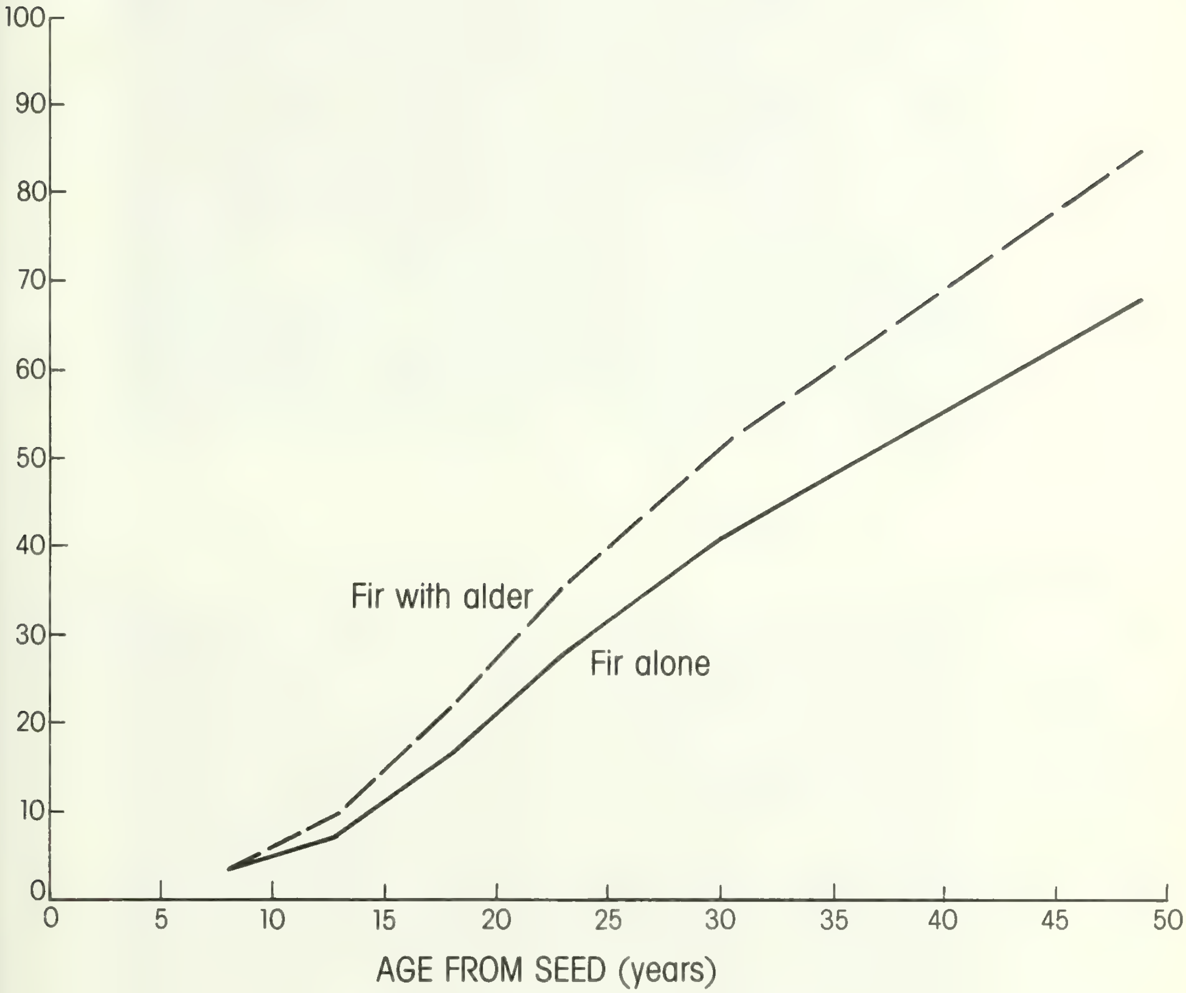

Figure 1.--Average height of dominant Douglas-fir in the pure and mixed stand at Wind River, data through 30 years adapted from Tarrant (10).

Figure 2.--A portion of the mixed plantation at Wind River. Note the 18-inch Douglas-fir to the left of center and the range pole beside it.

Figure 3.--A portion of the Douglas-fir plantation at Wind River. Note that the range pole in the center of the photo has 1-foot wide vertical bands.

Table 4--*Average distribution of tree numbers and volume by diameter class in 48-year-old stands at Wind River, per acre basis*

D.b.h. class (Inches)	Pure Douglas-fir	Mixed	
		Douglas-fir	Red alder
	- - - - - - -Number of stems- - - - - - -		
3	40	26	9
6	195	112	163
9	126	71	103
12	22	20	14
15	0	28	0
18	0	2	0
All	383	259	289
	- - -Cubic-foot volume, total stem- - - -		
3	49	30	27
6	943	451	1,010
9	1,414	835	1,216
12	490	474	285
15	0	1,141	0
18	0	179	0
All	2,896	3,110	2,538

In contrast, the mixed stand contained fewer, but larger, Douglas-fir. An average of 259 Douglas-fir remained or about two-thirds the number in the pure stand. Again, nearly one-half of these were in the 6-inch class. The most striking difference, however, was the presence of 50 Douglas-fir per acre in the 12-inch and larger diameter classes (table 4). Thirty of these could be called "superdominants"; they were present only in the mixed stand and were uniformly distributed. Sawtimber-sized Douglas-fir represented 58 percent of the total volume of Douglas-fir in the mixed stand compared to 17 percent in the pure stand (fig. 4).

Numbers and diameters of red alder.--The mixed stand averaged slightly more red alder trees than Douglas-fir. Again, the 6-inch diameter class was modal; it contained more than half the alder trees (table 4). An average of 14 alder trees per acre attained the 12-inch d.b.h. class, compared to 22 Douglas-fir in the pure stand. Recall that 50 Douglas-fir in the mixed stand also reached this 12-inch diameter class or larger. Despite greater stand density in the mixed stand, alder not only increased the diameter growth of associated Douglas-fir, but also attained sawtimber size.

Past Trends

Interplanting 1,200 alder seedlings per acre in a 4-year-old Douglas-fir plantation at Wind River increased competition. We estimated the effects of this competition by combining our recent data with earlier observations and published data (*10*).

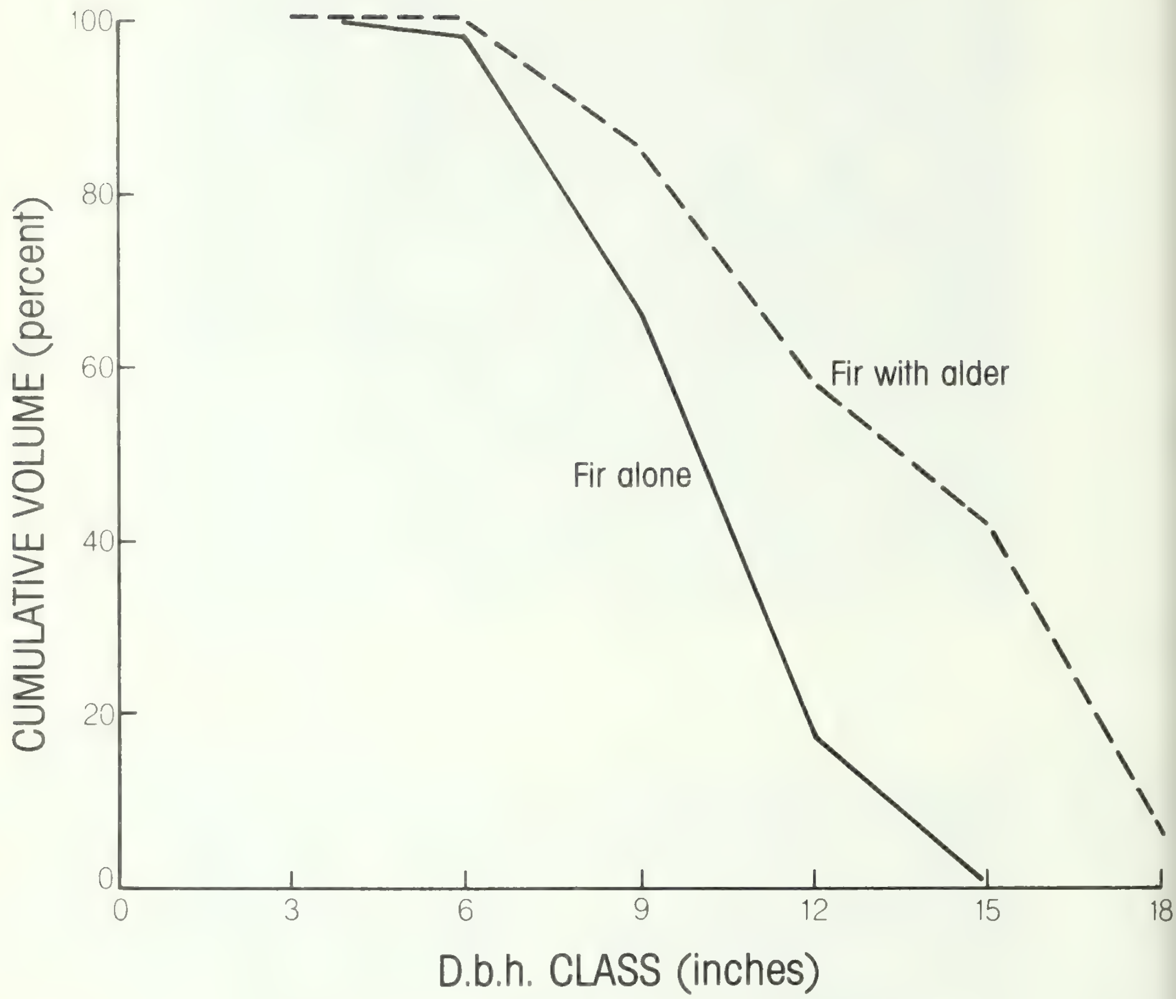

Figure 4.--Cumulative volume distribution by diameter class in 48-year-old Douglas-fir at Wind River.

Surviving trees.--Of the original 680 Douglas-fir planted per acre, an average of 383 or 56 percent survived in the pure stand compared to 258 or 38 percent in the mixed stand (fig. 5). This greater loss of Douglas-fir in the mixed stand could be anticipated since there were also about 1,210 alder seedlings planted per acre with no subsequent stocking control. The trends of surviving Douglas-fir are not parallel for the mixed and pure stands in either the 2- to 30-year period or the 31- to 48-year period. Th mixed stand had greater losses of Douglas-fir in both periods and particularly in the 2- to 30-year period.

Red alder losses exceeded Douglas-fir losses in the mixed stand. Of the original 1,210 alder seedlings planted, only 24 percent survived competition and environmental stress compared to 38 percent of the Douglas-fir. Although the off-site alder were severely damaged by frost shortly

fter planting, only about 10 percent of the alder seedlings were actually illed by frost. According to early records, sprouts arose from the root ollars of most frost-damaged seedlings. Therefore, supression was the more ikely cause of early mortality in the interplanted red alder.

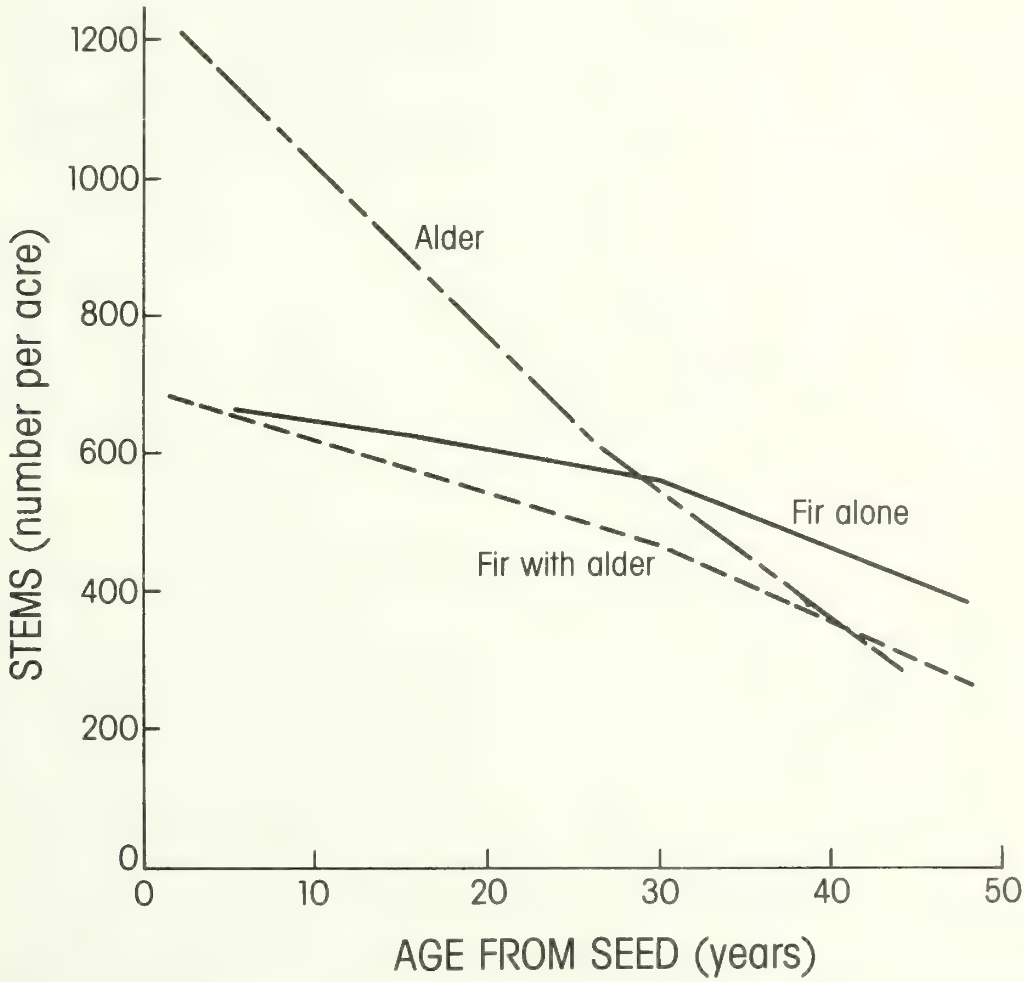

Figure 5.--Number of trees by species at Wind River.

Height-diameter relations.--We previously described the "superdominant" ouglas-fir in the mixed stand. These trees were taller and larger in diamter than Douglas-fir in the pure stand; they also towered above the alder anopy (fig. 6).

At 48 years of age, however, the crowns of about 70 percent of the ouglas-fir in the mixed stand were below the top level of the alder canopy. herefore, we anticipate additional mortality of suppressed Douglas-fir n the future.

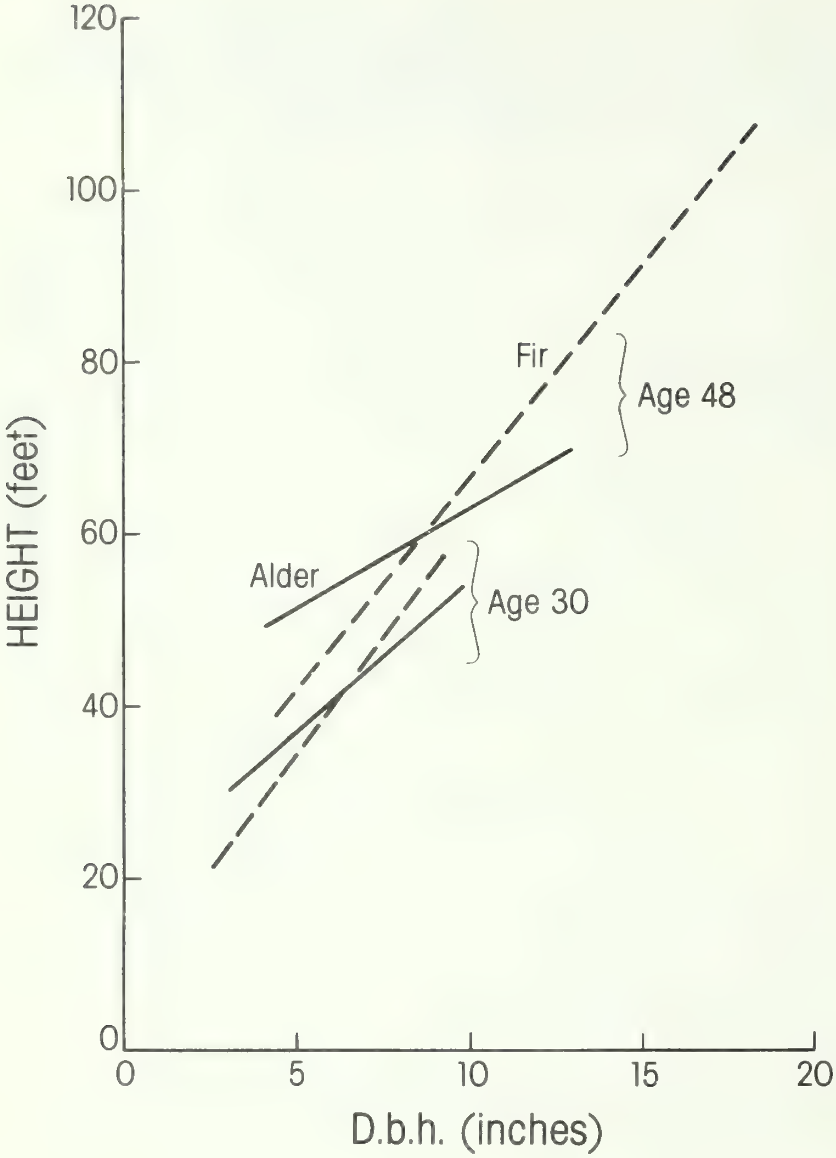

Figure 6.--Height-diameter relatio at age 30 and 48 years in the mixed stand at Wind River.

Based on earlier measurements (*10*), we believe that the dominant Douglas-fir began emerging from the alder canopy when they were about 30 years old. At 30 years for the Douglas-fir and 26 years for the alder, dominant trees of both species were similar in height and diameter (fig. 6 Eighteen years later, however, the dominant alder averaged less than 70 fe tall, while the dominant Douglas-fir exceeded 100 feet in height and were strikingly larger in diameter.

Diameter growth of dominant Douglas-fir accelerated about the time th emerged from the alder canopy or when they were about 30 years old (fig. 7 Although the beneficial effects on height growth occurred by year 18 (fig. the stimulating effects of red alder on diameter growth of Douglas-fir wer minimal until tree mortality had reduced stand density and the fir began emerging from the dominating alder canopy.

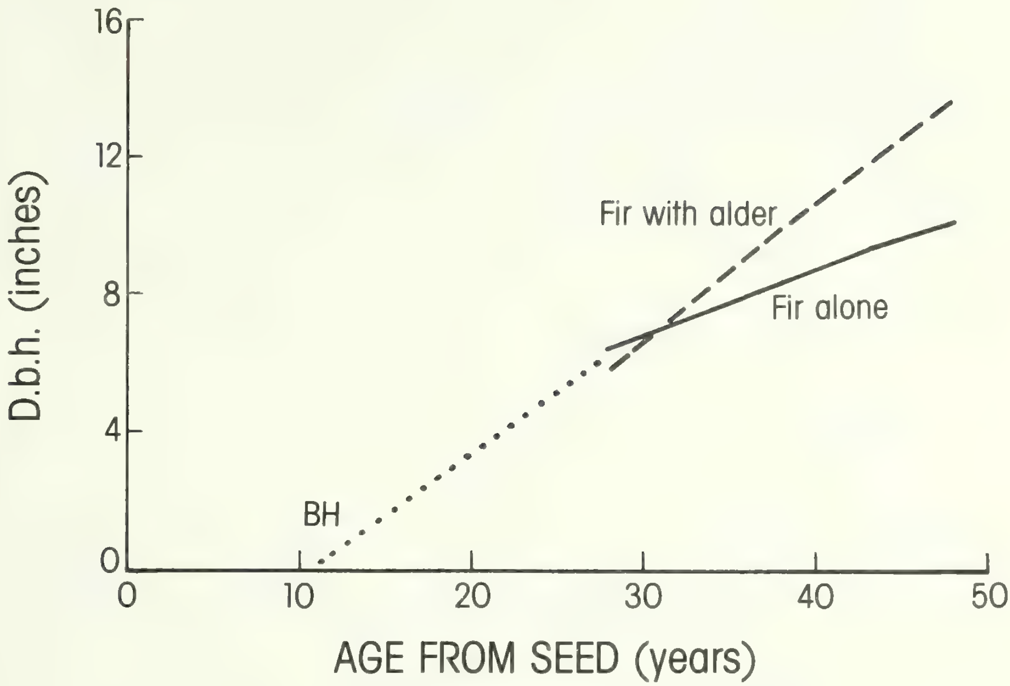

Figure 7.--Average d.b.h. of dominant Douglas-fir at Wind River.

Since these stands were left unmanaged, we can only assume that early hinning would have resulted in an earlier acceleration of diameter growth. ur findings at Wind River support earlier recommendations (*9, 13, 14*) of arly and effective control of spacing to improve survival and growth of rop trees.

Bole deformity.--Nearly one-quarter of the Douglas-fir in the pure tand had bole deformity at one or more places. This past leader or top reakage was likely caused by winter damage that frequently occurs in the ind River study area (*6*). Although the percentage of trees with bole de- ormity was more than twice as great in the mixed stand as in the pure, this eformity was not severe in most trees (table 5). Severe bole deformity was vident in 12 percent of the Douglas-fir in the pure stand and 10 percent in he mixed stand (table 5). We assumed that moderate and minimum deformity ould have little effect on bole volume above the point of deformity; there- ore, the reductions in bole volume will probably be nearly the same for oth stands.

The incidence of damage in the mixed stand was about the same for ouglas-fir and red alder. The greater incidence of past top damage in the ixed stand is most likely due to the closer spacing of the trees.

Table 5--*Average percentage of trees at Wind River with bole deformity*

Severity of deformity	Volume above point of damage	Pure stand	Mixed stand	
		Douglas-fir	Douglas-fir	Red alder
Maximum	Negligible	12	10	3
Moderate	Reduced	5	32	38
Minimum	Near normal	7	16	20
All		24	58	61

Applicability of Results

The severe N deficiency of the Wind River site probably accentuates t benefits of alder's nitrogen-fixing capacity. Therefore, the positive effects of alder are likely to be greater here than in most sites managed fo timber production. Moreover, this unique situation may not demonstrate th negative and competitive effects of alder under typical conditions. At Wind River the alder was an off-site seed source, was planted 4 years afte the Douglas-fir on a 6- by 6-foot spacing, and was badly frosted soon afte planting. In typical mixed stands, however, the alder is more site-adapte is equal in age to the Douglas-fir, and may have greater initial numbers o stems.

CASCADE HEAD, DELEZENNE, AND SKYKOMISH

We investigated even-aged, mixed stands at three locations to check th general applicability of our findings at Wind River.

Surviving Trees

Initial and final stand composition.--Mixed stands of naturally regenerated Douglas-fir and red alder vary in the proportion of these species t other conifers, especially shade-tolerant hemlock, western redcedar, and Sitka spruce. High initial densities of even-aged red alder usually reduce survival of Douglas-fir, a species that is intermediate in shade tolerance. Our sample stands illustrate these general concepts (table 6). An adequate stocking of Douglas-fir in the final stand occurred only if the initial alder component was minimal or removed in an early liberation cut, e.g., Cascade Head and Skykomish (figs. 8 and 9).

Trends in stand composition.--Trends of species composition are well illustrated by the long-term records for four Delezenne plots located on u form soil and topography (fig. 10). The number of Douglas-fir is closely correlated with number of red alder at stand age of both 30 and 53 years; the more red alder, the fewer Douglas-fir in the stand.

Table 6--*Changes in species composition in some even-aged mixed stands, per acre basis*

Area	Plot	Initial				Final			
		Age	Douglas-fir	Red alder	Both	Age	Douglas-fir	Red alder	Both
		Years	- - - - -Number- - - - - -			Years	- - - - -Number- - - - - -		
scade Head	11	9	436	1,010	1,446	42	54	290	344
	15	9	286	1,368	1,664	42	12	328	340
	17	9	454	(1/)	(1/)	42	188	0	188
ezenne	1	30	305	40	345	53	175	35	210
	4	30	235	110	345	53	140	95	235
	3	30	125	210	335	53	60	120	180
	2	30	70	270	340	53	45	150	195
komish	Mixed	2	960	444	1,404	20	492	420	912
	Pure	2	896	205[2/]	1,101	20	719	0	719

[1/] An unknown number of red alder were felled and the conifers thinned.

[2/] Red alder removed 4 years later.

Figure 8.--Twenty-year-old, mixed stand at Skykomish. Most Douglas-fir were overtopped by about 400 uniformly distributed red alder per acre. Note the range pole with 1-foot wide bands in the left-of-center foreground.

Figure 9.--A nearby portion of the Skykomish plantation. Alder volunteers were cut when the stand was 4 to 7 years old.

The coefficients describing these linear relations between Douglas-fi and red alder have practical implications for silviculturists.

Stand age	a	b	r^2
30	347	-1.03	0.99
53	226	-1.21	.88

Each red alder tree replaced 1.03 Douglas-fir at age 30 and 1.21 at age 53; the coefficients were not significantly different (P>.05). If we assume that the same relation between numbers of alder and Douglas-fir was linear over the full range of species composition, the a-coefficients indicate tha a pure stand of Douglas-fir at this location would have contained 347 stems per acre at 30 years and 226 at 53 years. Normal stands of this site inde and age contain 355 and 290 stems per acre (5).

Age of Emergence

Some Douglas-fir survived despite heavy initial stocking of red alder in most of these even-aged stands (table 6). Douglas-fir probably attained a dominant crown position and crop tree status in the fortuitous absence of strong alder competition.

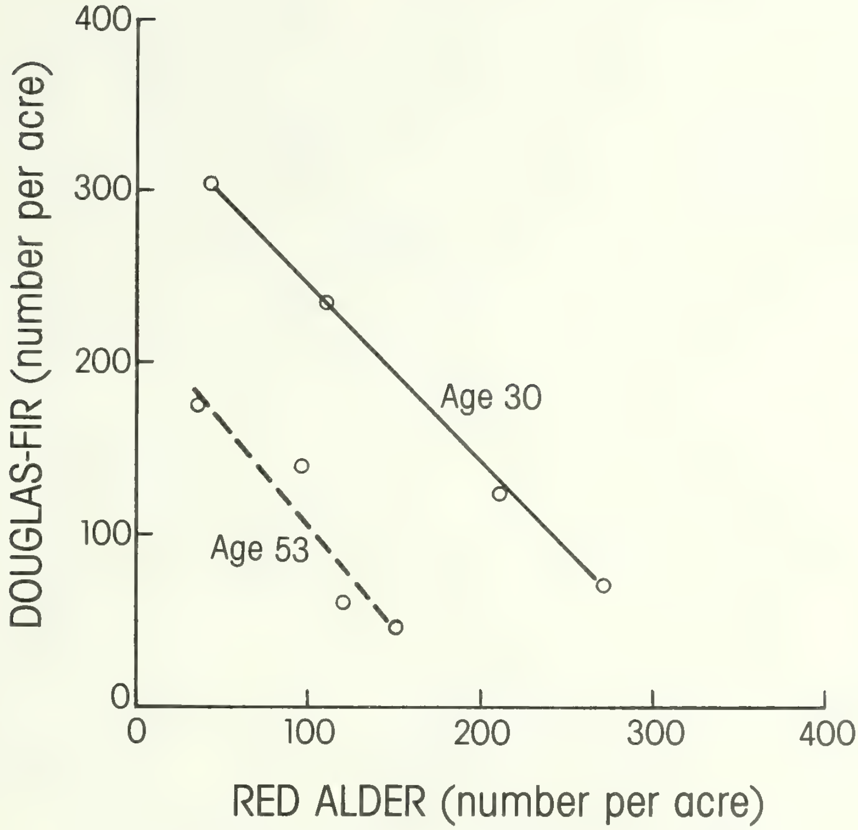

Figure 10.--Number of trees by species and age at Delezenne.

At the time Douglas-fir emerges through and above the alder canopy, its survival is usually assured. Recall that this emergence occurred at about 30 years in the two-aged Wind River plantation. The two natural, even-aged stands at Cascade Head and Delezenne represent typical conditions. Both show emergence and presence of "superdominants" at or before age 30 (figs. 11 and 12).

Height-diameter trends in these even-aged alder mixtures were similar to those in the Wind River plantation where the alder was 4 years younger than the Douglas-fir. The age of emergence in these even-aged stands was also similar to those reported earlier by Newton et al. (7). Based on early height growth trends of alder and Douglas-fir at numerous locations in western Oregon, they predicted that equal-aged Douglas-fir would attain dominance in mixed stands by 25 to 35 years on so-called "non-wet" sites and about 10 years later on wet sites where alder had a competitive advantage over Douglas-fir.

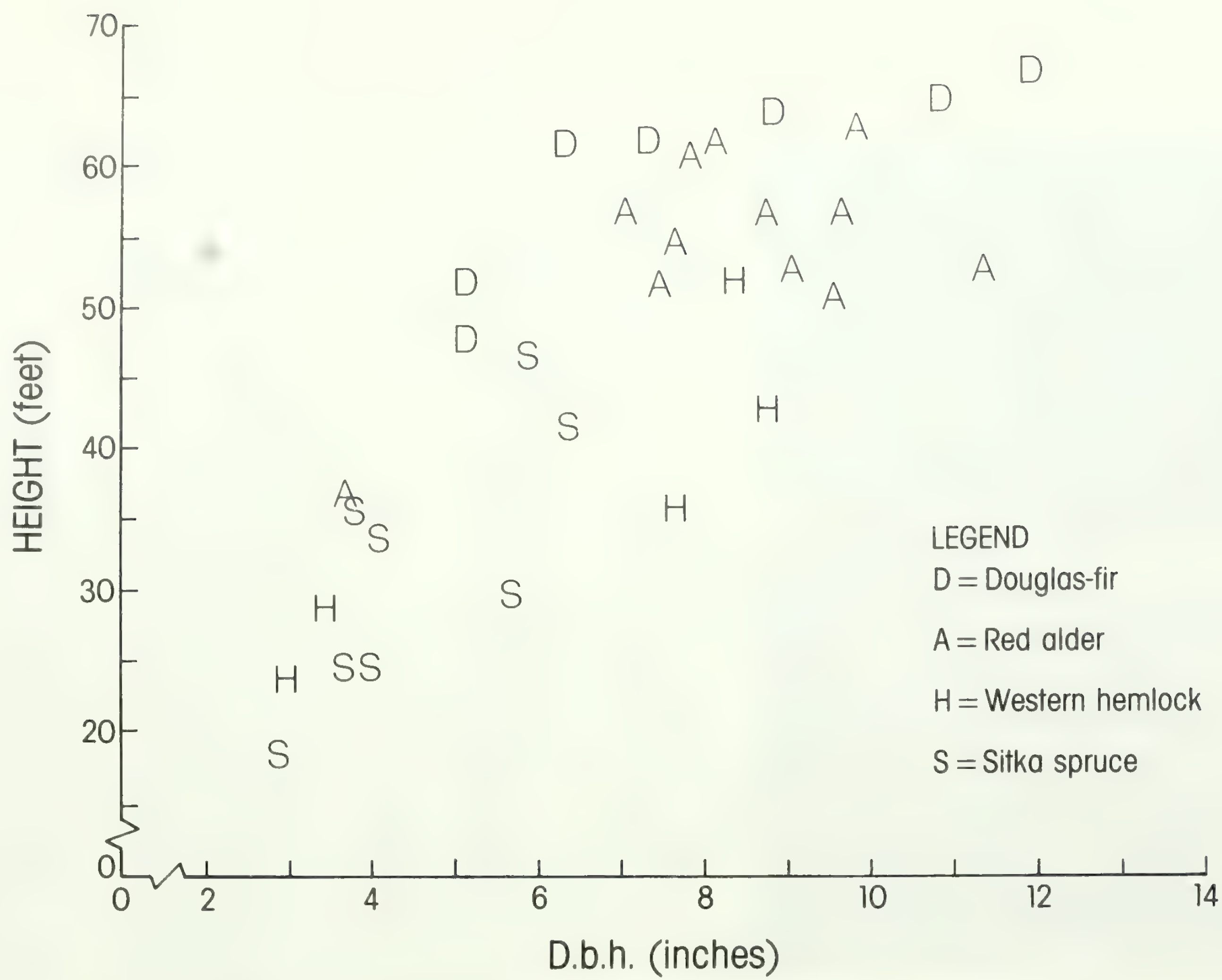

Figure 11.--Height and diameters of 30-year-old Douglas-fir and red alder in Plot 11 at Cascade Head.

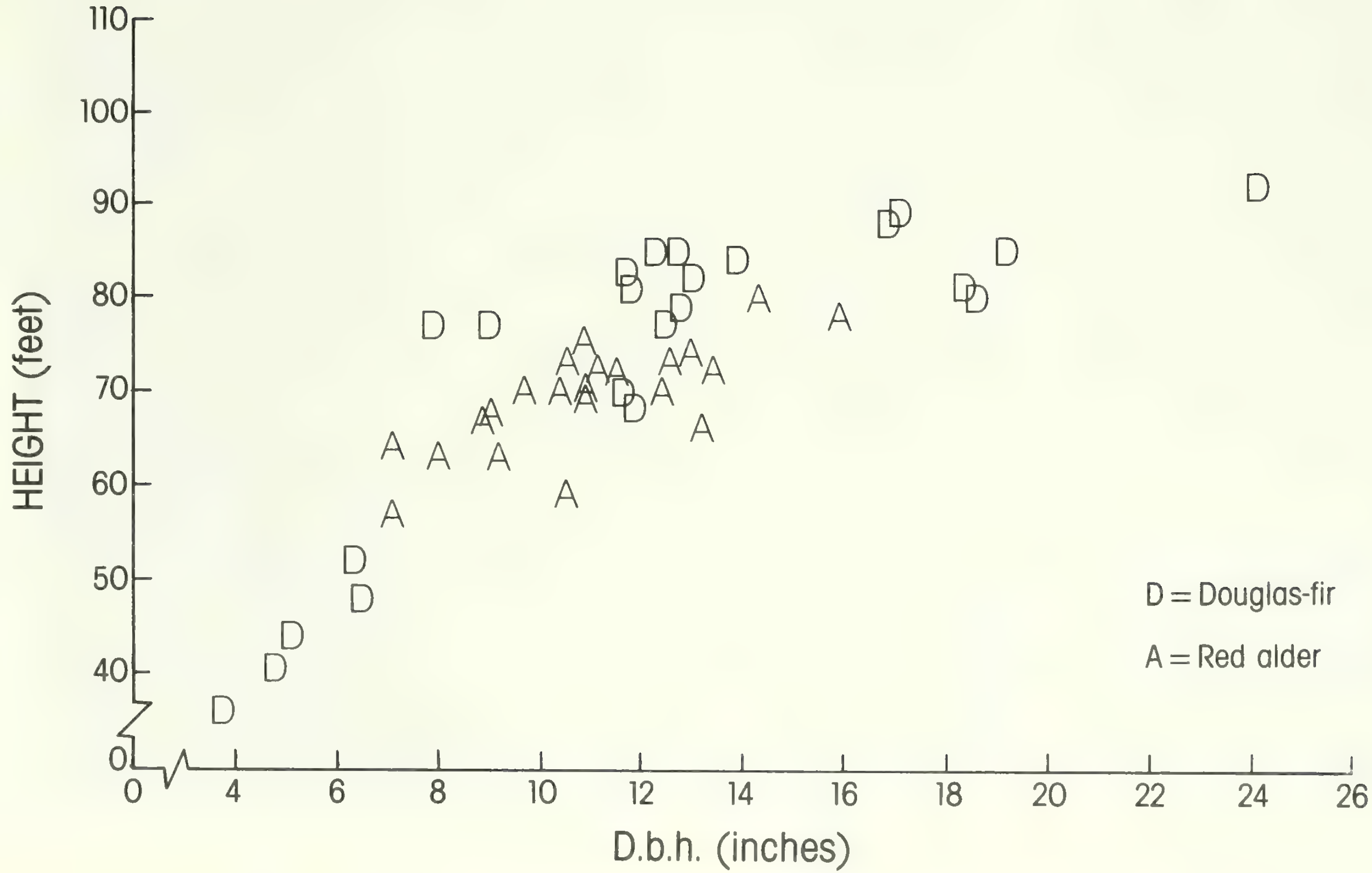

Figure 12.--Height and diameters of 30-year-old Douglas-fir and red alder in four plots at Delezenne.

MANAGEMENT IMPLICATIONS

To attain full stocking of Douglas-fir, foresters cannot rely on chanc survival and emergence of Douglas-fir crop trees in mixtures with red alder Full and uniform distribution of conifers will seldom be attained (fig. 13) Foresters recognize the competitive advantage of red alder over the more highly valued Douglas-fir and attempt to neutralize this by spraying mixed stands with herbicides. This treatment usually eliminates red alder as a potential crop tree and effective N-fixer. Paradoxically, however, foresters increasingly use nitrogen fertilizers to boost yields from Douglas-fir forests. To what extent could organic fertilization through N-fixing plant such as red alder substitute for inorganic fertilizers? What are the comparative costs and benefits? A key part of any analysis is determining the number of admixed red alder per acre necessary to maintain available nitrogen at optimal levels for growth of associated Douglas-fir.

These questions suggest we should compare two intensive management regimes for Douglas-fir. As tabulated below, our conventional regime controls volunteer red alder with a herbicide spray when the alder is about 5 years old. A subsequent precommercial thinning eliminates surviving alder and excess Douglas-fir. We assume that fertilizing with 200 pounds of N per acre at 10-year intervals will eliminate N as a growth-limiting factor. Commercial thinning starts at age 35 in both regimes.

Figure 13.--A 50-year-old mixed stand near the Delezenne study area. Note the clumpy and non-uniform distribution of Douglas-fir.

Silvicultural activities in two management regimes for Douglas-fir plantations with red alder volunteers

	Regime	
Nominal age	Pure stand	Mixed stand
(Years)		
0	plant	plant
5	apply herbicide	stocking control
15	control stocking, fertilize	
20		stocking control
25	fertilize	
35	thin, fertilize	thin
45	thin, fertilize	thin

In our theoretical, mixed-stand management regime, early stocking control eliminates surplus trees of both species; all red alder that will not overtop Douglas-fir crop trees until a second precommercial thinning at age 20 are retained. The second thinning will leave a minimal number of uniformly spaced red alder in a dominant or codominant position to insure high rates of N fixation and to minimize bole sweep. Although these red alder will subsequently be harvested, their major purpose is to eliminate the need for fertilizers by maintaining or improving soil nitrogen and organic matter status for optimal growth of associated Douglas-fir.

The number of red alder to leave is critical to any economic comparison of the two regimes, because each red alder will replace at least one Douglas-fir that would probably provide a greater economic return. We recognize this species difference in future value at harvest as an "opportunity cost" of using red alder instead of commercial fertilizers. Clearly, the financial attractiveness of the mixed stand regime will increase if (1) the stumpage price of red alder improves relative to that of Douglas-fir and, (2) the cost of fertilization increases.

What is the minimum number of red alder crop trees to retain in the mixed stand for adequate N production? The fewer red alder retained, the lower will be this opportunity cost. At the N-deficient site at Wind River, we noted that Douglas-fir in the pure plantation that were within about 30 feet of the mixed stand were noticeably larger than those at farther distances. This suggests maintaining red alder in a mixed stand at a 60-foot spacing or 12 per acre. More than 12 will probably be necessary, because an individual red alder is not likely to be as influential as a group like we observed at Wind River. For improving nitrogen and organic matter status in Douglas-fir stands, we recommend 20 to 40 uniformly distributed, dominant red alder per acre. This number should not seriously reduce Douglas-fir growing stock.

Conclusions

1. Red alder increased height and diameter growth of associated, dominant Douglas-fir on a nitrogen-deficient site at Wind River.
2. The Douglas-fir, which were planted 4 years before the off-site alder, emerged through the alder canopy at 25 to 30 years from seed. Before this canopy separation, dominant Douglas-fir in the mixed stand were taller than those in the pure stand but had about the same diameter.
3. After emergence, dominant fir accelerated height and especially diameter growth. Within the next 20 years, some of the dominant fir in the mixed stand had attained 18-inch d.b.h compared to 13 inches for their counterparts in the pure stand. Moreover, 40 dominant Douglas-fir per acre averaged 20 percent taller than thos in the pure stand.
4. Red alder increased sawtimber yields of associated Douglas-fir at Wind River. Moreover, some of the off-site alder trees reached sawtimber size. The total volume of the mixed plantation was nearly twice that of the pure Douglas-fir plantation.
5. The natural, even-aged stands at Cascade Head and Delezenne Creek represented typical conditions. Both showed emergence and presenc of superdominant Douglas-fir at or before age 30.
6. An adequate stocking of Douglas-fir in the final stand occurred at our three locations with even-aged mixed stands only if the alder component was initially minimal or reduced to this by an early liberation cut.
7. Creating or maintaining red alder in Douglas-fir stands is a potential means for increasing merchantable yields from nitrogen-deficient sites.
8. The benefits of red alder or other N-fixing plants will probably be greatest on soils that are deficient in total or available nitrogen and low in organic matter and clay. Because nitrogen fertilizers have frequently increased growth of Douglas-fir over a wide range of sites in western Washington and Oregon, it is like that N-fixing plants will also improve growth over a similar wide range of sites.
9. Controlling growing stock at an early age to keep Douglas-fir crop trees in a dominant or codominant position and to favor crop trees of both species will improve the benefits from mixed stands.
10. We recommend that 20 to 40 uniformly distributed red alder per acre be maintained in a dominant position to improve nitrogen and organic matter status in Douglas-fir stands.

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SILVICULTURAL IMPLICATIONS OF THE RECONSTRUCTION OF MIXED ALDER/CONIFER STANDS[1]

GEORGE STUBBLEFIELD, Graduate Student
College of Forest Resources
University of Washington
Seattle, Washington

CHADWICK D. OLIVER, Assistant Professor
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

Mixed alder/hemlock/redcedar/Douglas-fir stands which began growth after a 1927 logging fire were studied on till soils of the Marckworth Forest of the central Washington Cascades. The stand was always sparsely stocked. Essentially all stems had begun within 20 years of the disturbance. Red alders were the same age or up to 17 years younger than the associated conifers on the same plot, although the conifers were usually in a subordinate position. For analyses of site index, stocking, and growth rates, it cannot be assumed that the alders are the same age as the initiating disturbance. The alders varied widely in crown size and diameter but varied less in height. Basal area of individual alders was closely related to spacing. Closely spaced alders resulted in spindly stems of poor quality. Very recent alder stands generally begin with many more stems per acre than this stand did. Early thinning may be necessary to achieve adequate alder growth.

Introduction

Mixed stands of red alder (*Alnus rubra* Bong.) and conifers became wide- established in western Washington, Oregon, and British Columbia after :ensive logging and frequent fires in the early 1900's. Approximately 5 million acres of alder and mixed alder-conifer stands exist in the ·thwest (Yoho et al. 1969), often on soils with the greatest potential for

[1]This study was supported in part by McIntire-Stennis Grants Nos. 61-9961 and -9964 to the College of Forest Resources, University of Washington. The study s done on lands managed by the Department of Natural Resources of the State of shington.

conifer volume growth. Alder is commonly associated with western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn.), and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). Many of these naturally seeded stands are of low value compared with pure conifer stands because of their relatively low volume and because unmanaged alders often have poor stem quality. Occasional natural alders of good stem quality and large diameter can be found. This study reconstructed the growth and competition patterns causing the development of alders of both good and poor quality. Two large alder/conifer stands approximately 50 years old were examined. Groups of alders and conifers with a range of sizes and stocking characteristics were selected. The trees in each group were simultaneously dissected, and the past growth patterns were reconstructed to determine the conditions leading to the observed variety of present stand structures. From these reconstructions of past growth patterns, silvicultural recommendations are made.

Study Area

The study was done on the Gordon D. Marckworth Experimental Forest in the foothills of the central Cascade Range of western Washington. In the 1920's, this land was owned and railroad logged by the Cherry Valley Logging Company. A large fire in about 1927 burned much of the cutover land and forest which now lies within its boundaries. Within a few years, the remaining timber was exhausted and the land claimed by the State for tax-delinquency. This land is now managed jointly by the Washington Department of Natural Resources (DNR) and the University of Washington.

The study was done mainly in Sections 35 and 20 (fig. 1). Elevation of the plots varied from 700 to 1,000 feet. The soils are mixtures of glacial till, residual materials, and ash. Site class for Douglas-fir is II- to III+.

Procedures

Thirty-one circular sample plots of one-fiftieth acre each were established in red alder-Douglas-fir timber types as mapped by the DNR. After stocking, stem quality, and crown classes were examined for each species on all plots, six plots were singled out for more intensive study. These six plots covered the range of alder and conifer stocking encountered; diameters of the alders on these six plots ranged from 5 to 18 inches. First, the six intensive study plots were examined for minimum estimates of mortality by intensively searching the litter. Next, each area was mapped for location of live and dead stems. Crown areas were then projected onto the ground and mapped. All plot trees and those trees whose crowns overlapped crowns of the plot trees were felled. Sections were cut at: the base, 1.0 foot, 4.5 feet, 8.0 feet, and every 4.0 feet thereafter. All disks were brought to the lab and aged as described below. All trees were cut in the winter of 1976-1977.

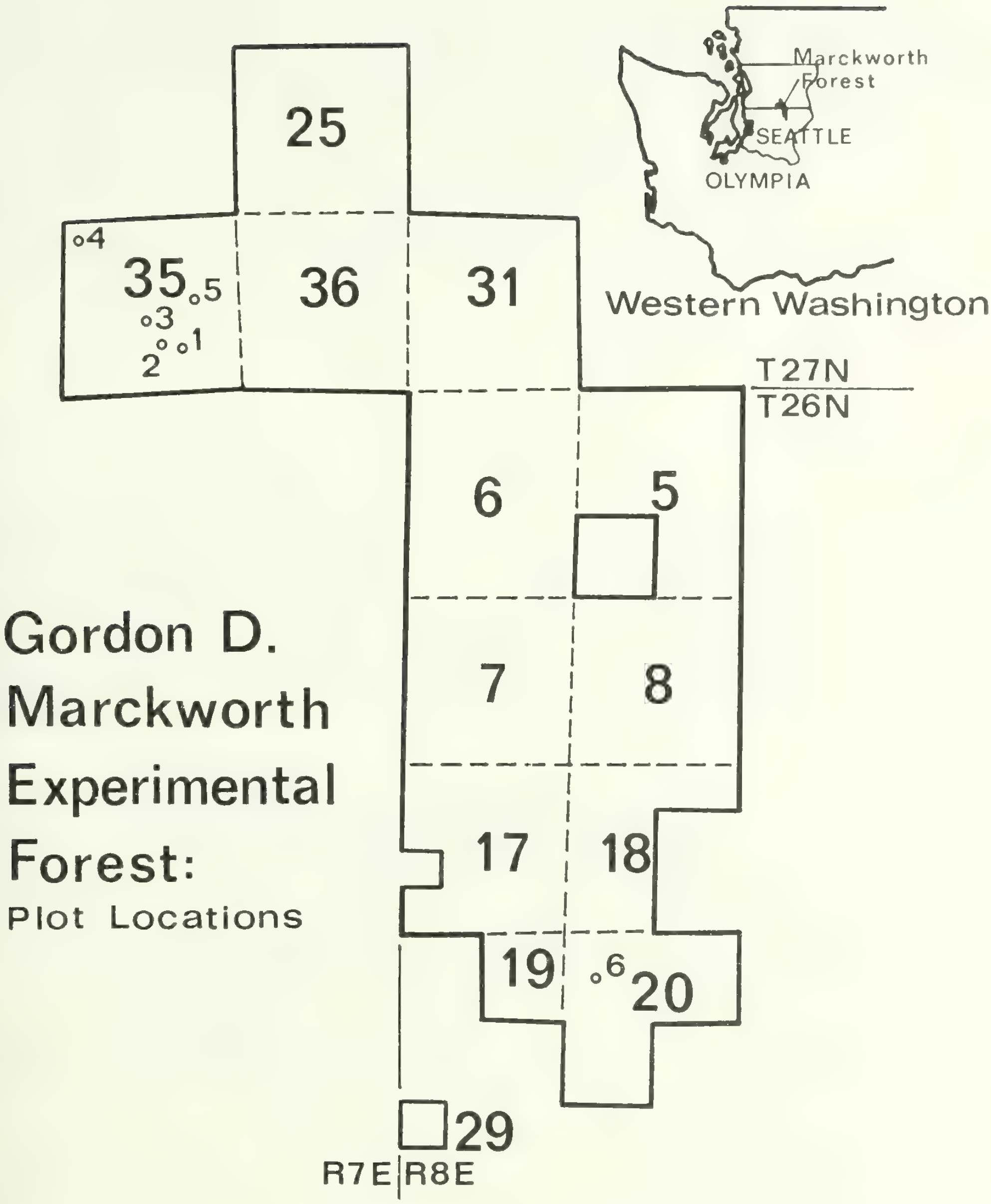


Figure 1.--Location of the six reconstructed plots on the Marckworth Forest and location of the Marckworth Forest in western Washington (inset).

It is known that trees when suppressed often do not produce an annual ring over the entire bole of the tree (Larson 1956, Bormann 1965)[2]; therefore, it was necessary to find a way to account for potentially nonexisten rings. It was possible to date disks by locating the annual ring produced following the freeze of November 1955. The rings produced during the 1956 growing season were generally much smaller, irregular, or had abnormal amounts of summerwood. On many of the alders a black line was found betwe the growth rings of the 1955 and 1956 years. When the 1956 ring was locat it was known that 20 years existed outside of it. The rings inside of thi were generally large enough so that "missing rings" were unlikely; the exceptions were a few small hemlocks. It is also possible that disks younge than 21 years could have dropped rings which were unnoticed.

Results and Discussion

STOCKING

Table 1 shows the estimated number of living stems and total number o stems per acre by species, based on intensive searches of the litter for dead stems. All of the stands sampled appeared to be initially sparsely stocked and of natural regeneration. The initial stocking of conifers was only 346 stems per acre. On each acre, 59 Douglas-fir appeared to seed in initially; but of these, only 18 per acre remained after 50 years. At mos there were only 160 alders per acre; however, others which might have exis could already have rotted away.

Table 1--*Number of stems of each species living at 50 years, and estimate of total number of stems, living and dead, since stand initiation based on analyses of stumps and other evidences in six plots*

Species	Total dead + alive	Number alive at 50 years
	Per acre	
Douglas-fir	59	18
Red alder	160	114
Western hemlock	123	64
Western redcedar	164	105
Cherry	119	0
Maple, willow	27	9
Total	652	310

[2]Oliver, C. D. 1975. The development of northern red oak (*Quercus rubra* L.) in mixed species, even-aged stands in central New England. Ph.D. dissertation, Yale University School of Forestry and Environmental Studies, New Haven, Conn. Appendix 4B:178-180.

DISTRIBUTION

Figure 2 shows the age distributions by species for the studied trees and surrounding the six plots. The age pattern was not as anticipated. alders were larger than most associated conifers. Rather than the ers being older than the conifers, however, they invaded after the con- rs on five of the six plots. In fact, they were up to 17 years younger n the first invading conifers. The greatest difference in alder ages a single plot was 5 years. The alder ranged in age on all six plots m 51 to 30 years with the mean age being 37.7 years. A similar pattern wide range of alder ages has been found in several stands near Olympia Bell and Wilson 1978). Johnson et al. (1926) reported the ability of ers to invade sites which were not completely restocked with conifers.

Hemlock and cedar were generally as old as or older than alder. An eption was one hemlock on plot 1 (fig. 2) which had started upon a ting stump. Including Douglas-fir, the conifers had a range of ages of to 41 years, the average being 45.5 years. Douglas-fir were found liv- g on or near only those plots in which they had started 10 years prior to e alder (this pattern has been found previously by Newton et al. 1968). ts 1 and 2 each had standing dead Douglas-fir which appeared to have died m competition with the alder. This delay in the alder invasion may be portant to the establishment of Douglas-fir in natural mixed stands. It probable that no Douglas-fir would be found on the site if the alders d all invaded when the first conifers did.

Figure 3 shows height growth patterns of selected trees representing e species and canopy positions found in this study. In spite of the unger ages of the alders, they were found to overtop most of the other nifers (fig. 3). When in competition with western redcedars, the alders re mainly in dominating positions. A 10 to 12 year delay in the alder vasion was necessary for cedar to reach the upper canopy when grown with der (unless the cedar were allowed sufficient spacing to gain the neces- ry height advantage before the alders closed in).

Hemlock did outgrow alder at times if the alder was delayed 8 to 10 ars.

DER GROWTH PATTERNS

Figure 4 shows the height growth of the tallest alder on the six plots. (he dominant alder growths of plots 4 and 6 were averaged because their ight growths and ages were very similar.) Growth of red alder appeared vary between plots with height growth curves tending to steepen with creasing length of delay of alder invasion. Plot 5 was an exception. The der here was shorter, perhaps because of less optimum soil conditions; her species on this plot were also shorter.

The heights reached by the dominant alder in most cases were similar d not related exclusively to age. Except for plot 5, it is assumed that ere is no major influence of site on growth between these plots. The

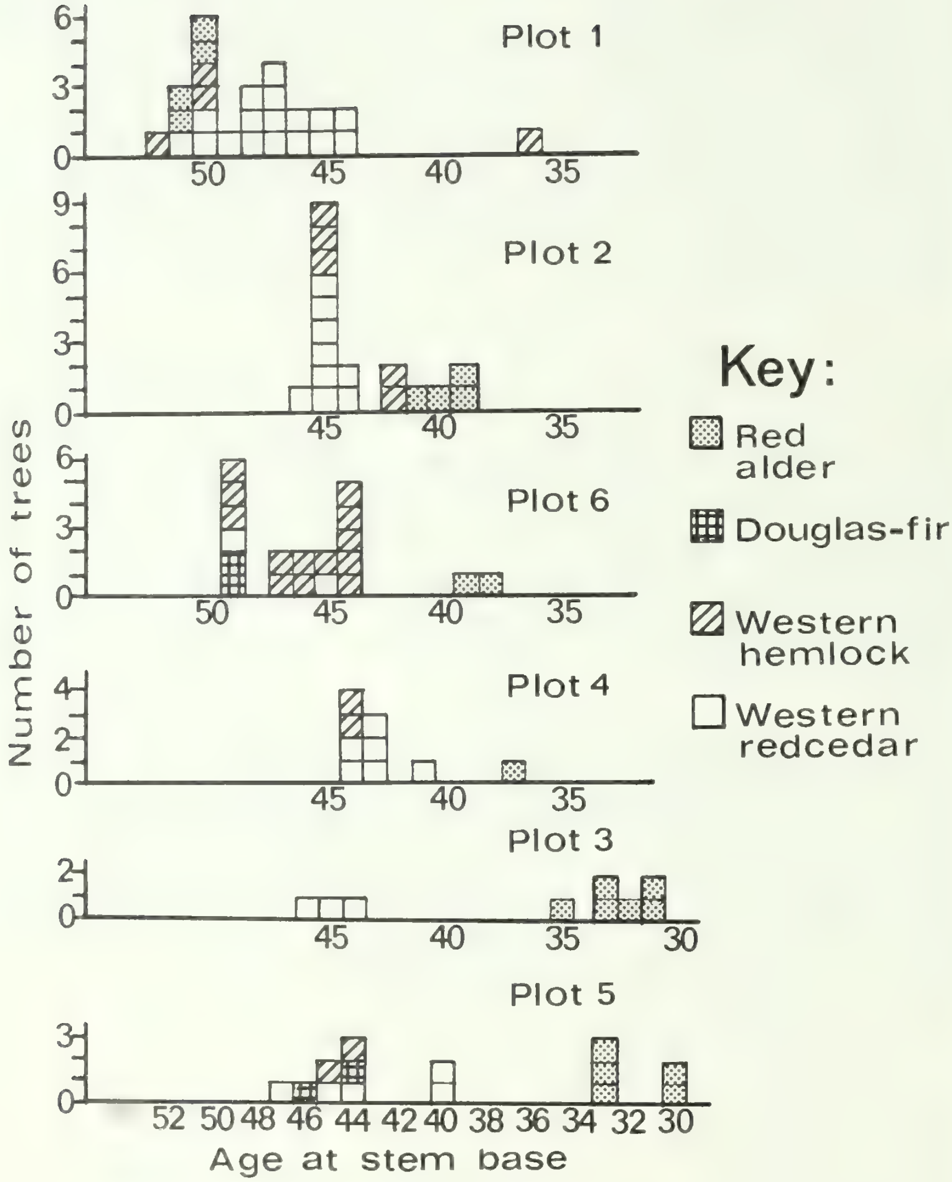


Figure 2.--Age distribution of stems by species for the studied trees on and surrounding the six plots. Plots are shown in order of delay of alder invasion.

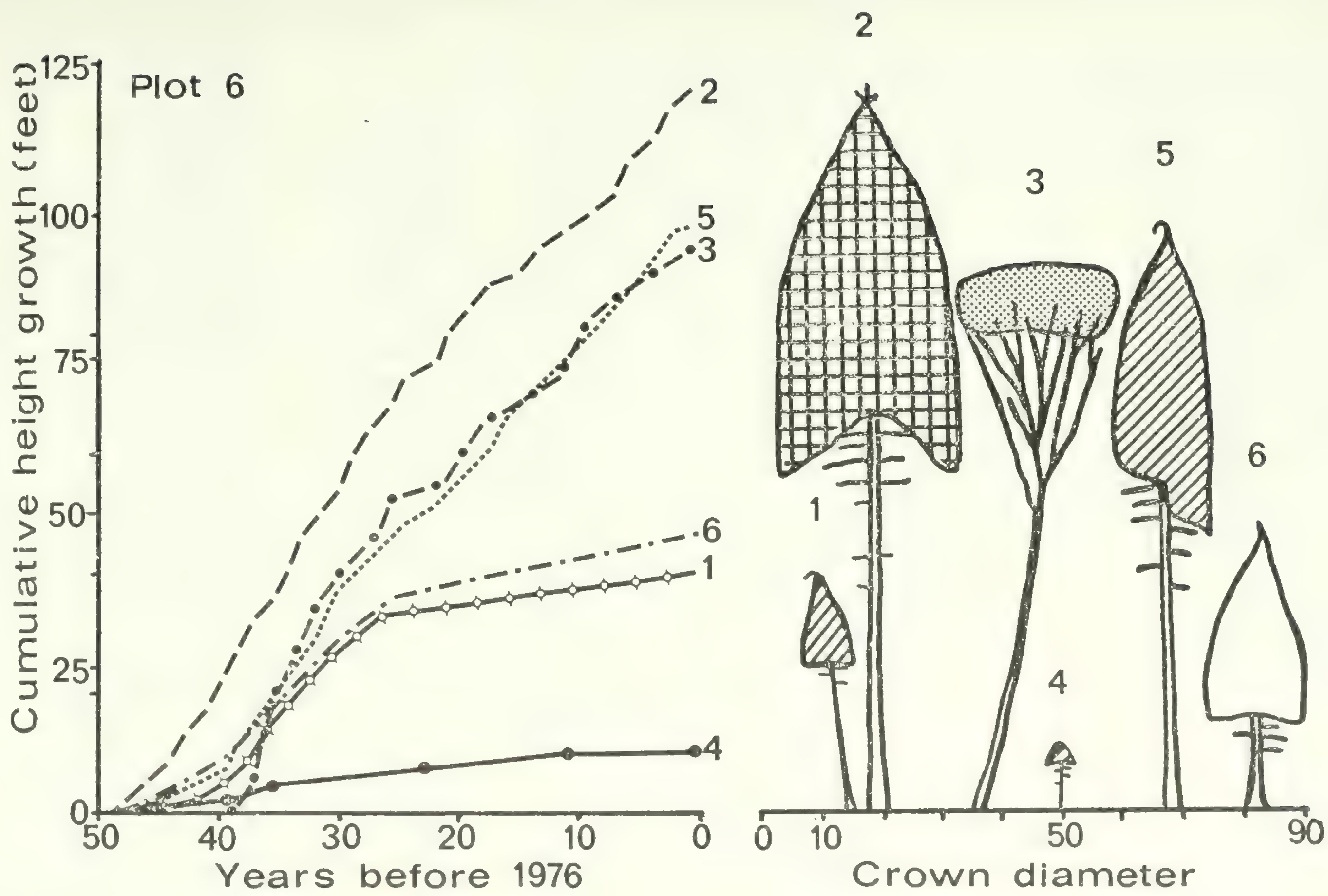


Figure 3.--Height growth patterns of selected red alder (dotted crown), Douglas-fir (gridded crown), western hemlocks (oblique-lined crowns), and western redcedar (blank crown), representing typical height growth patterns and canopy positions.

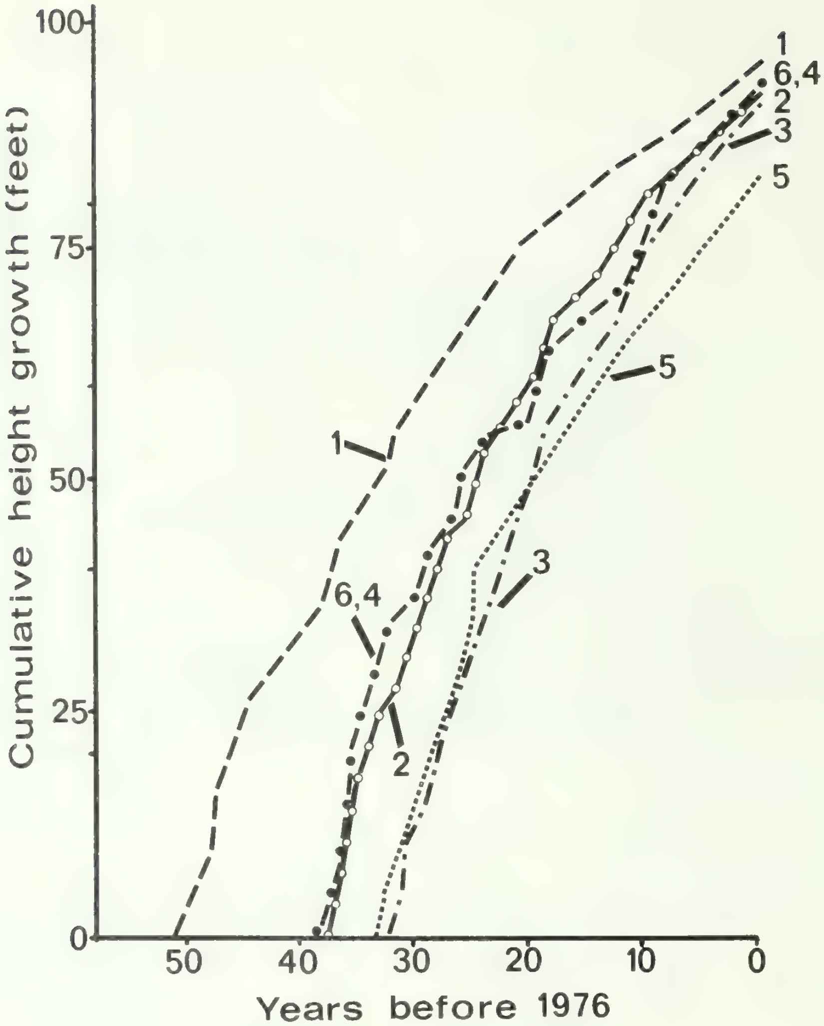


Figure 4.--Height growth pattern of the tallest alder on each plot studied. Height growths of the tallest alders on plots 4 and 6 were averaged because their patterns and times of initiation were very similar.

younger alder grew with more competition from the sides. Consequently, their height growth potential may have been concentrated more strongly into their terminals, rather than developing large lateral branches as well. Diameter growth, however, was reduced on the younger dominants. Figure 5 shows diameter growth patterns of the same five alder shown in figure 4. The restricted crown size of the younger alder may have resulted in more rapid height growth but decreased diameter growth.

The younger alder, about 30 to 35 years of age, typically had slender, twisted, and leaning stems, small crowns, and poor form. This does not mean, however, that alder cannot also be suppressed.

Within each plot, height growth patterns were similar while diameter

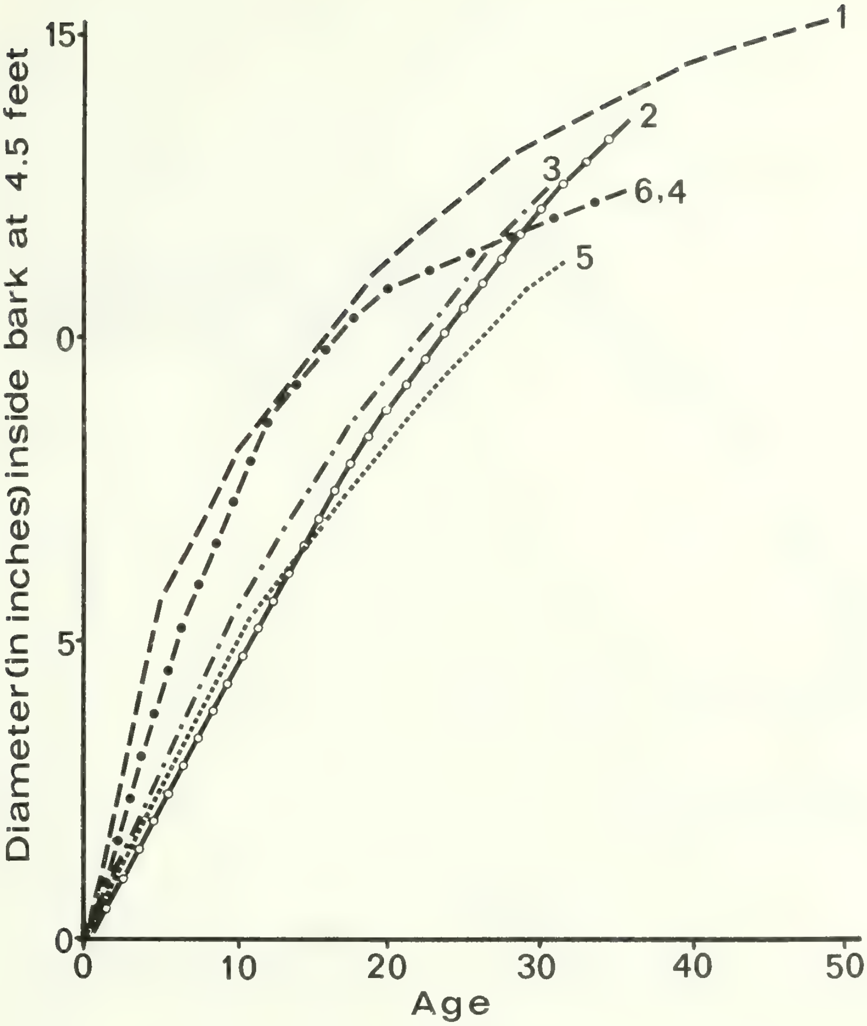
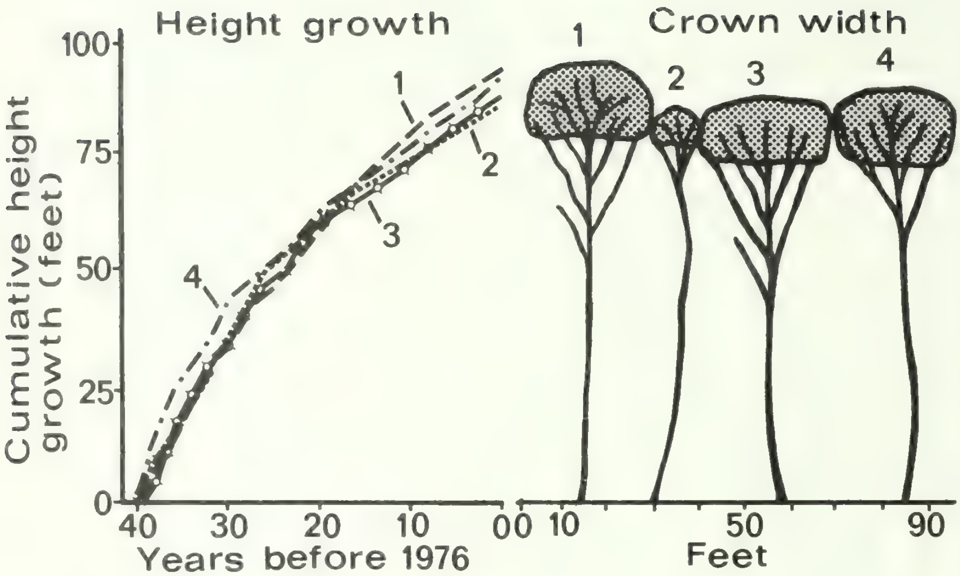
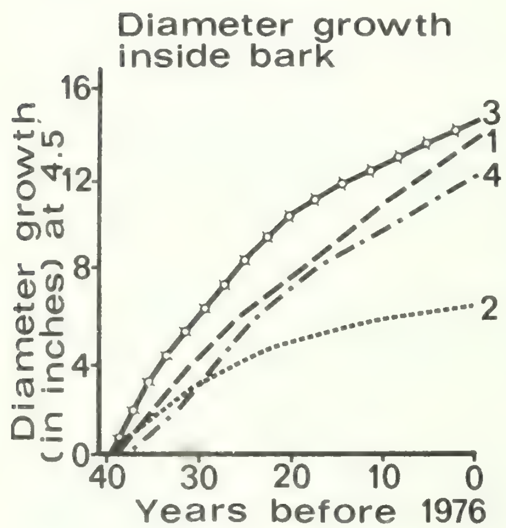


Figure 5.--Diameter growths (breast height, inside bark) of the alders shown in figure 4.

owths varied greatly. Figure 6 shows this for plot 2. There is a simi-
rity in height which seemed relatively unaffected by the crown width.
is striking similarity of height growth could lead to the stagnation ob-
rved in other studies (Haddock 1948, Warrack 1949).

Diameter growths, however, were directly related to crown sizes. Fig-
e 7 shows the relation of crown surface area projections to basal areas
all the alder examined.





	Height	d.b.h. (in.)	Crown area (feet²)
1	92′11″	14.9″	673
2	84′11″	7.2″	99.3
3	88′ 9″	15.8″	727
4	91′ 8″	12.5″	502

Figure 6.--Height and d.b.h. growth patterns and present canopy sizes of all four alders found within one plot. Height growths are very similar; however, crown sizes and diameter growths vary markedly.

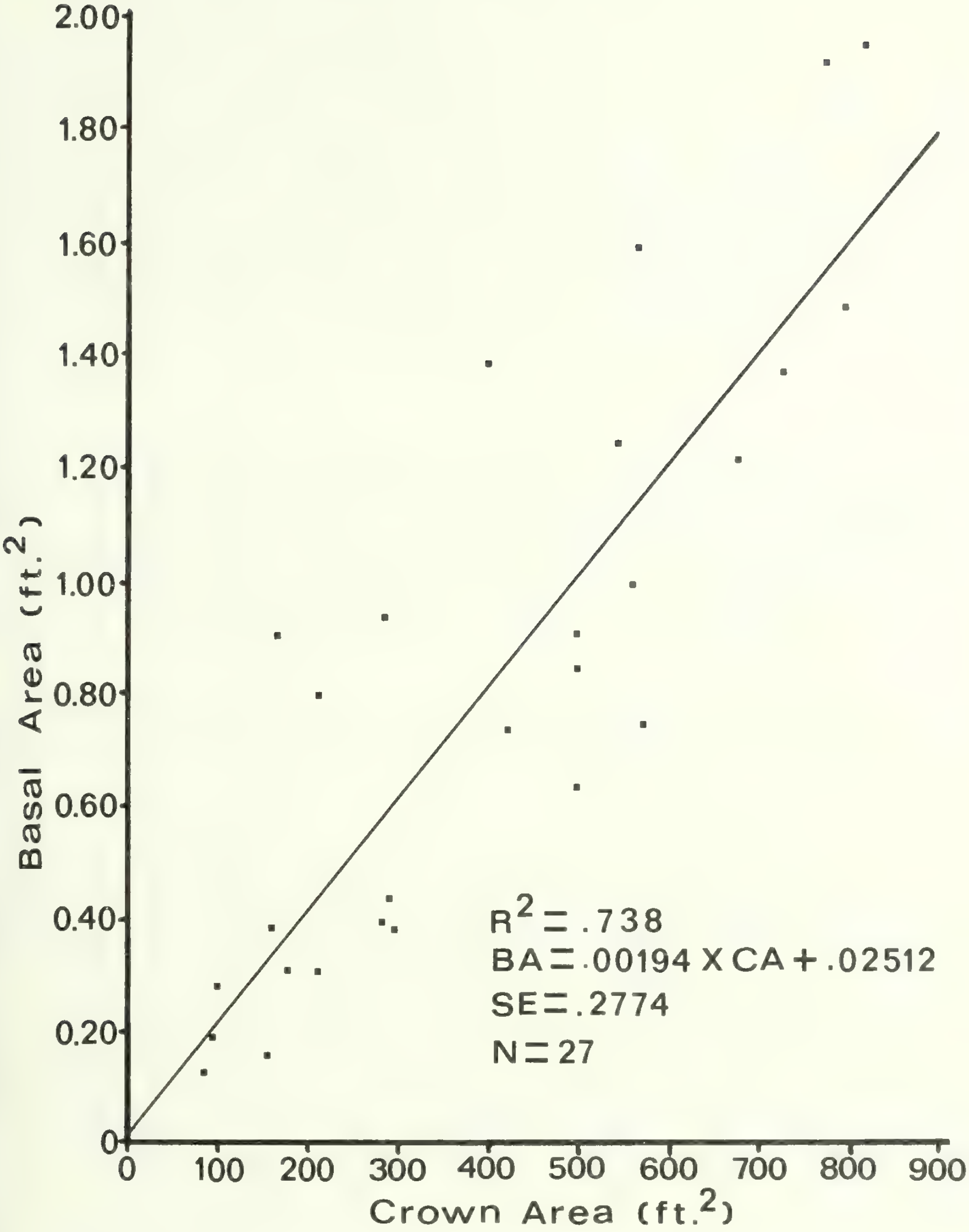


Figure 7.--Relation of individual tree basal area (BA) at breast height to surface area (CA) of the crown projection of the 27 red alders studied.

Silvicultural Opportunities

PURE STANDS

If it is desirable to establish conifers, alder should be eliminated until crown closure of the conifers or until they have a 10-year head star Intensive use of herbicides is one possibility which presently has varied success. Another alternative may be dense planting of conifers with later precommercial thinnings. With only 350 stems per acre of conifers initial in this study area, the alder were able to invade over an extended period. The future pattern of alder invasion on these sites may be different since an alder seed source now seems readily available over these lands. The ability of alder to overtop conifers permanently, however, may disappear o poor sites.

If alder is acceptable as a crop tree, natural stands may not be acceptable. Natural stands can be of wide age ranges and have poor stocking Other stands may be so dense that acceptable yields may not be possible without intermediate operations. Precommercial thinnings should be delaye until alder are 6 to 7 years old since new recruitment by seeding will the probably be shaded out. Sprouting may still be a problem. Alder can (if given the chance) produce stems of 10- to 15-inch diameters on rotations o 30 years or less.

Any estimate of site in these natural stands can be confounded by the differences in age and by the wide variation of observed growth patterns.

MIXED STANDS

Mixtures of alder, hemlock, and cedar may also be desirable. These stands can be grown by allowing all three species to enter at the same tim alder will grow above the other two species on good sites. Several silvicultural opportunities are possible.

Cedar grown beneath alder can reduce the brush normally associated wi alder. This will reduce site preparation costs during subsequent rotation even if the cedar are not commercially harvested. Cedar could also reduce the limbiness and improve the quality of alder. In fact, discussion at th conference revealed that alder grown with conifers are preferred over alde grown in pure stands. Any cedar volume gained would be a bonus.

Instead of one harvest operation, it may be desirable to remove the alder overwood when the alder reaches a merchantable size. Hemlock and cedar, which it appears can be released from suppression (Oliver 1976), ca then be encouraged as a second crop. Presently, this practice is being followed in parts of Europe with aspen (*Populus* sp.) overwoods and Norway spruce (*Picea abies* [L.] Karst.) being the tolerant understory conifer (IUFRO 1976).

It appears that cedar are better suited than hemlock or Douglas-fir i

. two-stage stand such as this. Douglas-fir cannot tolerate the shade. lemlock did not appear capable of as much height or diameter growth as cedar vhen in the understory. Some of the hemlock which did grow into the over-story lacked sufficient diameter growth to support their spindly stems upon removal of the alder. Several of these had already bent over in the pres-ent stands because of lack of stem support.

In natural mixed stands, we observed that the occasional Douglas-fir which did dominate the alder often were becoming emergent wolf trees. To ise these trees as a measure of site index could be misleading since growth can be increased by nitrogen additions from the alder (Tarrant 1961, Miller and Murray 1977). Also, growth is at times decreased since these exposed crowns become knocked out by winds, frosts, and other storms. One Douglas-fir, whose crown was 30 feet above the alders, had its top knocked out three times. Another, which was 15 to 20 feet above the alders, had lost its leader twice.

On accessible lands it may be possible to plant Douglas-fir in rows spaced about 12 feet apart. Alder could be encouraged between these rows and controlled by silage harvests until the firs are tall enough (about 12 feet) to survive any subsequent growth or invasion by alder. In this way, short-term returns could be gained with the silage harvest. Nitrogen would also be added to the site while the alder are being controlled.

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BIOLOGICAL COMPONENTS OF ALDER YIELD IMPROVEMENT[1]

JOHN C. GORDON
Department of Forest Science
School of Forestry
Oregon State University
Corvallis, Oregon

ABSTRACT

Although alder has not been extensively used in intensive forestry, its potential is great. Two species, Alnus rubra *Bong. and* Alnus glutinosa *(L.) Gaertn., are particularly promising because of their growth habit, characteristics, and having been studied more than other alders. The concept of ideal plant type, or ideotype, is useful in determining the yield potential and the need for improvement in specific characteristics of crop plants.*

When alders are compared to an ideotype for maximum yield of fiber, they fit well--rapid juvenile growth, ease of vegetative propagation, crown shape, growing season utilization, nitrogen fixation, microbiological relations, genetic variation, and early flowering are all positive. Characteristics with poorer fit are water relations, unit-leaf-area rate of photosynthesis, fecundity, and wood properties. These, however, are susceptible to some genetic and cultural improvement. Recent studies have shown, for example, that photosynthetic capacity and the ability to fix atmospheric nitrogen are closely related but that considerable genetic variation exists in both characteristics.

Introduction

Although alders have not been extensively used in intensive forestry, their potential seems great. Their rapid juvenile growth and their ability to fix atmospheric nitrogen symbiotically recommend them as components of intensively cultured forests. In the Pacific Northwest, alder currently is an abundant, cheap, little-used resource. Elsewhere, however, alder culture is being seriously explored (7). If alder is to be exploited as a forest crop plant in the Pacific Northwest within the next 20 years, we should begin now to understand its growth and development and to estimate its potential for improvement. The purpose of this paper is to discuss alder (based on studies of *Alnus rubra* and *Alnus glutinosa*) as improvable plant material in relation to its potential role in intensive forestry.

[1]This is paper 1178. For. Res. Lab., Oregon State University, Corvallis.

Ideotype

Ideotype, or ideal plant type, is a concept useful in tree and crop improvement. To use the concept, one must design, *a priori*, ideal stand participants for an explicit production goal. There is not, of course, any unique ideal plant type, even of a single species. Rather, many ideotypes, dependent on production goals, can be designed for many purposes. For example, designs for ideal participants in stands grown for maximum yield of biomass would differ from those intended for maximum yield of wood fiber. Ideal stand participants for the production of larger diameter individuals to be used for veneer or sawlog production would differ markedly from either maximum biomass or wood fiber yield ideotypes. Ideotypes for alder intended for use as a nurse crop probably would differ from all these.

Here, I compare the properties of alder to a generalized ideotype for maximum yield of wood fiber (*2*). The major attributes of this ideotype, which assumes dense stands carried over short rotations, are:

(1) full utilization of the growing seasons by meristems from the time of stand establishment;

(2) laterally compact crown and root system, with high proportional investment of photosynthate in cambial activity, and minimum investment of photosynthate in reproduction processes and structures;

(3) high rate of photosynthate production;

(4) maximum production of dry mass per unit of environmental input (water, nutrients);

(5) easy vegetative propagation by cuttings and by sprouting after harvest;

(6) maximum genetic variation and early flowering, to allow rapid genetic improvement; and

(7) wood properties suitable for a wide range of fiber products.

Both *Alnus rubra* and *Alnus glutinosa* fit this general ideotype reasonably well. Both show rapid juvenile growth (*6, 8*). Biomass growth rates of young *A. rubra* stands exceed those published for any other North American woody species.[2] Both *A. glutinosa* and *A. rubra* stumps sprout readily after cutting when young, although *A. rubra* is said to lose this ability after about age 20 years.[3] *Alnus glutinosa* propagates readily from greenwood stem cuttings (*1*). Its use of the growing season is good also because it seemingly remains photosynthetically active well into the fall, as evidenced by retention of green leaves. Both *A. glutinosa* and *A. rubra* are wide ranging

[2] N. Smith, University of British Columbia, Vancouver, BC, personal communication.

[3] M. Newton, Oregon State University, Corvallis, Oregon, personal communication.

and should include great genetic variability. Alders are noted also for early flowering. Seed-to-seed is possible in 2 years. Perhaps the most interesting positive feature of the alders is their ability to fix atmospheric dinitrogen. This process is not without cost; considerable quantities of photosynthate are required to support the high energy demands of nodular nitrogenase activity. Alders, however, can apparently contribute high quantities of fixed nitrogen to the soil while sustaining rapid rates of growth (9).

Poorer fit to the ideotype exists for several characteristics. Alders are seemingly prodigal of water. McVean (6) states that stomatal control of transpiration is poor in *A. glutinosa*; *A. rubra* appears to be more mesic in its site requirements than *A. glutinosa*. Unit-leaf-area rates of photosynthesis are not high in *A. glutinosa (3)* nor in *A. rubra (5)*. Alders are usually prolific seed producers, and to the extent that this is not useful for reproduction or genetic improvement, it represents wastage of photosynthate from productive processes.

Overall, both red and black alder fit the generalized maximum fiber yield ideotype closely, and both are genetically variable enough so that less desirable characters could be improved. Improvement should be rapid once undertaken because of the alder's capability for vegetative propagation and for early flowering and seed set. One of the most intriguing aspects of potential alder improvement is the possibility of genetic variation in the endophyte organism that causes nodulation of alder roots. There may be optimum combinations of host and endophyte genotype that would result in more efficient nitrogen fixation.

Photosynthesis and N_2 Fixation

One of the best reasons for regarding alder as an important, improvable forest crop plant derives from the relation between photosynthetic capacity and dinitrogen fixation rate. For both soybeans *(4)* and alders (*3*), enhanced photosynthesis seems to lead to higher rates of dinitrogen fixation. If this is so, then attempts to increase dry mass yields by enhancing photosynthesis rates should have a double effect. First, enhanced photosynthesis should, of itself, increase rate of dry matter accumulation. Second, increased dinitrogen fixation should improve the nitrogen status of the plant. This, in turn, should increase the size and duration of the plant's leaf area, which would provide a further photosynthate increment. Studies with *A. glutinosa* clones show that large differences exist among clones in rates of photosynthesis and nitrogenase activity, and that the two are positively correlated (r=0.86) (table 1). If these findings are confirmed for larger plants, alders could be selected for accumulation of rapid dry mass and high rates of simultaneously dinitrogen fixation.

Table 1--*Rates of photosynthesis and acetylene reduction, nodule fresh weight, and total plant dry-weight means for each of 12* Alnus glutinosa *clones*[1/]

Clone (number)	Acetylene reduction ($nmoles \cdot h^{-1}$) per plant	Acetylene reduction ($nmoles \cdot h^{-1}$) per g nodules[2/]	Photosynthesis per plant ($mg\ CO_2 \cdot hr^{-1}$)	Nodule fresh weight (g)	Total plant dry weight (g)
5-50	335	386	12.80	0.98	5.29
3-25	266	473	10.90	0.55	4.30
3-23	188	533	8.80	0.40	3.79
1-23	179	332	9.30	0.54	4.28
2-50	157	161	11.80	1.02	4.89
2-58	151	275	8.80	0.52	4.10
3-13	142	352	2.90	0.26	2.11
6-15	133	228	6.80	0.58	3.25
6-12	127	232	7.60	0.57	3.21
5-37	123	171	0.86	0.67	3.05
4-40	38	276	6.60	0.14	2.81
3-21	25	92	6.50	0.15	2.79

[1/] Clone numbers are for identification only, with the first number designating the seedlot and the second, the individual plant from which the clone was propagated. Each tabular value is the mean of three observations.

[2/] Fresh weight.

Future Research

Perhaps the most important task for future research in the improvement of alder yield is to better understand the host-endophyte interactions. In particular, a search for optimum combinations of host and endophyte genotype should be launched. The gathering of endophyte from a wide range of habitats and its application to a known set of clonal alders would give a rapid indication of whether growth rate gains could be expected from larger trials. At the same time, a full range of alder genotypes should be collected, examined for fit to carefully constructed ideotypes, and used in breeding experiments to see whether a closer approach to ideotypes is possible. The silvicultural systems that gave rise to the ideotypes should be field tested with improved alders on a variety of sites representative of those where alder culture is contemplated. Of course, such a program is desirable only if we intend to use alder as a component of intensive silviculture in the Pacific Northwest at some future time. Many of its biological properties indicate that this would be a sensible thing to do.

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COMPARATIVE MINERAL CYCLING IN RED ALDER AND DOUGLAS-FIR

DALE W. COLE, Professor
College of Forest Resources
University of Washington
Seattle, Washington

S. P. GESSEL, Professor
College of Forest Resources
University of Washington
Seattle, Washington

JOHN TURNER, Research Scientist
N.S.W. Forestry Commission
Wood Technology Division
Beecroft 2119
New South Wales, Australia

ABSTRACT

*A comparative study of mineral cycling between second-growth forests of red alder (*Alnus rubra*) and Douglas-fir (*Pseudotsuga menziesii*) was made at the Thompson research site within the Cedar River watershed, western Washington. Both sites have similar histories and are adjoining on glacial drift material. The rate of elemental cycling is far faster in alder than in Douglas-fir. The red alder ecosystem is accumulating 85 $kg \cdot ha^{-1} \cdot yr^{-1}$ more nitrogen than the Douglas-fir, apparently through biological fixation. Greater percentages of the nutrients are stored within the trees and understory vegetation in the alder ecosystem, but these nutrients remain within the foliage and forest floor two to five times longer in Douglas-fir than in alder. Nutrient leaching losses are slightly higher within the alder ecosystem. This study helps clarify the role of red alder in second-growth forests and provides insight into the management of this type of ecosystem.*

Introduction

The biological merits of mixed softwood-hardwood forests emerged with le development of intensive forestry in Germany. Experience with pure rains of Norway spruce on sandy soils of northern Germany has led silviculturists to strongly recommend mixtures of hardwoods with conifers or rdwoods in place of conifers. As with many biological forestry problems, wever, there is no simple solution because pure stands of beech can lead podzolization. Obviously, the nature of the problem relative to pure or

mixed stands depends on the characteristics of the species and the nature of the forest environment, especially the soil.

These brief historical aspects are introduced to provide a setting fo a discussion of the impact of red alder and Douglas-fir with respect to mineral cycling in northwest forests. The same concerns relative to pure stands frequently have been voiced in northwest forestry and red alder has been advocated as a species to provide a softwood-hardwood mix. Alder doe have several merits for this purpose and most of these are already known t the audience making up this symposium. The principal advantage reported f red alder is its nitrogen-fixing ability and therefore the contribution of significant amounts of this element to our generally nitrogen-poor environments.

The higher nitrogen content of red alder litter not only provides for rapid buildup of soil nitrogen but also leads to a more rapid decompositio rate of organic material in the soil and forest floor. This change in the soil nutritional status and decomposition rates affects many additional properties of the soil system including the microbiological populations, release of minerals, and rates of leaching.

While it is true that both alder and Douglas-fir can occupy similar sites in the Pacific Northwest, many times as a mixed-species forest, they have little else in common. It is a purpose of this paper to assess some of the differences between the species, especially as they relate to the rate of cycling and accumulation of nutrient elements. Specifically, the following comparisons have been made:

1. Rate of elemental accumulation occurring within the major compartments of these ecosystems. From this comparison we will calculate the rate and location of nitrogen accumulation associated with an alder forest.
2. Rate of elemental transfer between major compartments within these two ecosystems, including rates of inputs and losses. This comparison provides us with an estimate of the relative capacity of these systems to conserve, store, and recycle nutrients.
3. Rate of elemental turnover in the foliage and forest floor compartments of these systems. From the comparisons we can estimate the length of time that nutrients remain within these two major ecosystem compartments.

It is our opinion that these results have a significant application t the management of forests in the Pacific Northwest.

The red alder and Douglas-fir stands compared in this article are situated on the Cedar River watershed in western Washington. These forest are adjoining each other on similar glacial drift materials. The study si is at approximately 230-m elevation, 64 km southeast of Seattle. Both stands have had similar histories. The entire area was harvested by clearcutting nearly 50 years ago. Frequent fire passed through the site until

98, when the Douglas-fir plantation was established. Alder naturally eded itself to the Douglas-fir plantation boundaries, thus the forest is composed of two nearly pure stands, one of alder, the other of Douglas-. It has been assumed that the differences currently found in the accu-ation and cycling in these two adjacent ecosystems are caused by the getation and do not predate the establishment of these stands. From tree ng analysis and from the forestry inventory records of the City of Seattle er Department, the Douglas-fir forest is now 47 years old. A ring anal-s of the alder indicates a minimum age of 38 years.

Methods

Details of the field installation necessary for making the many measure-ts associated with these studies of mineral cycling have been described earlier articles. The basic plot design, site description, and environ-ntal monitoring systems are discussed by Cole and Gessel (*1*). The lysim-er system for collecting soil solutions is further detailed by Cole and ssel (*2*).

Necessary chemical analyses were completed in laboratories at the lege of Forest Resources at the University of Washington. Soil nitrogen s analyzed by the Kjeldahl procedure. Soil potassium and calcium were termined with an atomic adsorption spectrophotometer (Instrumentation boratories 353) following extraction with ammonium acetate. Organic ples such as foliage, wood, and forest floor were initially digested ing a lithium sulfate modification of the Kjeldahl procedure (*5*). The rogen in these digestions was then determined with a Technicon Auto-alyzer (model II), and the potassium and calcium determined by atomic sorption.

Results and Discussion

For the purposes of the comparison, three elements have been selected--rogen, potassium, and calcium. Nitrogen is the most critical element in e assessment in that it is in deficient supply within the Douglas-fir stem and has been added to the alder system through a fixation process. assium and calcium were selected because of the relative mobility of ese two elements. Potassium is not associated with structural materials the plants and does not have to be mineralized to be released from or-nic substrates, thus it is highly mobile. Calcium, by contrast, accumu-tes in the older tissues, typically as a sulfate oxalate precipitate, and therefore highly immobile within plant tissue. Theoretically, these two ements also behave differently within the soil solution because of dif-rences in valence and ionic size.

It is evident through a comparison of nitrogen, potassium, and calcium cumulation and redistribution that alder and Douglas-fir have structured rikingly different ecosystems during this 38- to 48-year period. For ample, in a 38-year period red alder has accumulated an additional 2 180

kg/ha of nitrogen over that found for Douglas-fir (table 1). Although most of this accumulation can be found in the soil and forest floor, the total aboveground vegetation in the red alder ecosystem also contains large quantities of nitrogen (690 kg/ha)--an amount over twice that found in the associated vegetative component of the Douglas-fir ecosystem. A significan portion of this accumulation (100 kg/ha) is contained in the understory, which is largely a dense sword fern population.

We found no marked difference between red alder and Douglas-fir ecosystems in relation to total potassium and calcium accumulation by the vegetation (table 1). More of the total is contained in the subordinate vegetation of the red alder system (table 2), however, partly because of the greater density of subordinate species under red alder than under Douglas-fir, and also because of the high potassium (and, to a lesser exten calcium) concentrations in the tissue of sword fern. The red alder ecosyst consistently contains a greater percentage of its elemental distribution above ground than that found for Douglas-fir (fig. 1).

Table 1--*Elemental distribution in red alder and Douglas-fir ecosystem (kg/ha)*

Element/ecosystem	Vegetation	Forest floor	Soil (exchange)	Soil (total)
Nitrogen				
Douglas-fir	330	180		3 270
Red alder	690	880		5 450
Potassium				
Douglas-fir	230	30	240	71 500
Red alder	230	90	140	77 200
Calcium				
Douglas-fir	340	140	740	98 800
Red alder	400	390	840	96 600

Table 2--*Distribution of elements within the vegetative components of red alder and Douglas-fir ecosystems (kg/ha)*

Element/canopies	Douglas-fir	Red alder
Nitrogen		
Overstory	320	590
Understory	10	100
Potassium		
Overstory	220	100
Understory	10	130
Calcium		
Overstory	330	300
Understory	10	100

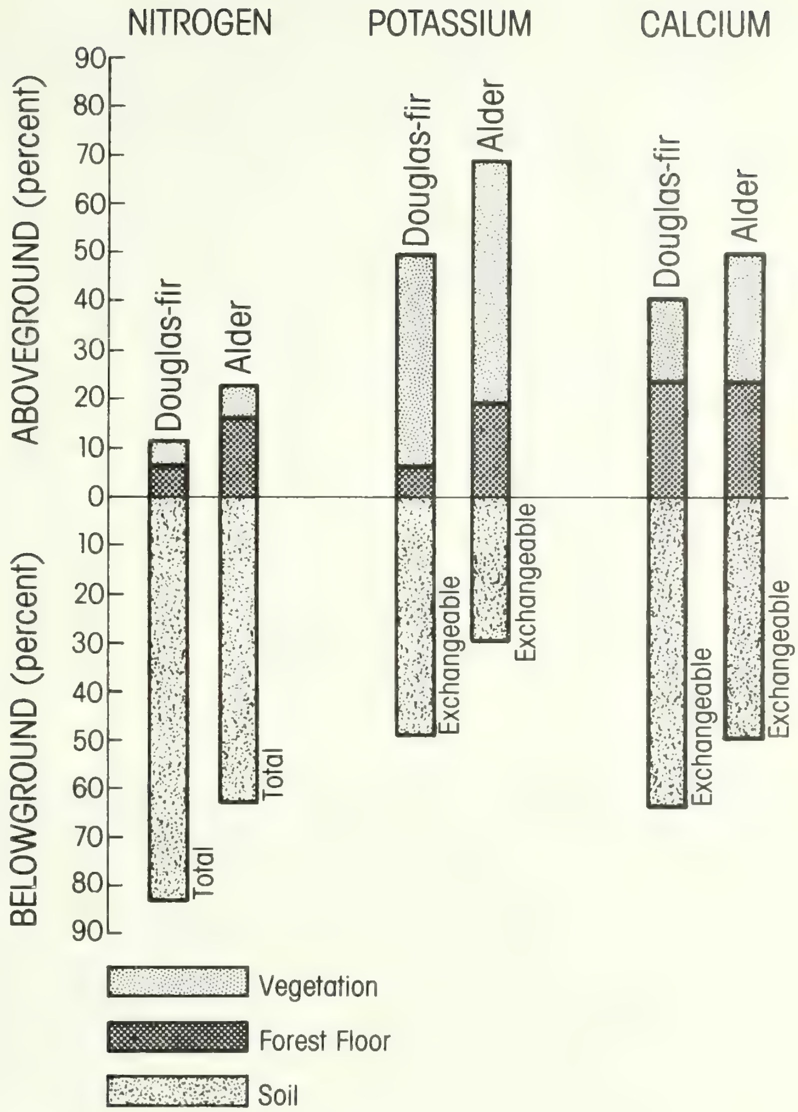

Figure 1.--Elemental distribution in red alder and Douglas-fir ecosystems.

Our data allow us to estimate the average annual rate of nitrogen accumulation[1] in red alder stands. During the approximate 38-year period of alder growth on this site an average annual nitrogen accumulation of 8.3 kg/ha has occurred. This annual increment of nitrogen is distributed within all the ecosystem components, with 57.4 kg in the soil, 18.4 kg in the forest floor, and 9.5 kg in the overstory and understory vegetation (table 3). This rate of nitrogen accumulation is not inconsistent with

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[1]Nitrogen accumulation in the alder ecosystem is defined as the net difference in nitrogen content between the alder and Douglas-fir ecosystems.

other values reported in the literature. Tarrant and Miller (1963) calculated an average annual accumulation of 41 kg/ha over a 30-year perio of alder occupancy relative to Douglas-fir occupancy of similar sites. Newton and co-workers (1968) have reported an extremely high value of annu accumulation of 321 kg/ha over a 15-year period of alder occupancy on site near the Oregon coast.

Table 3--*Estimated nitrogen accumulation and average annual accumulation by 38-year-old red alder (kg/ha)*

Vertical Zone	Estimated N accumulation		Increase in red alder over Douglas-fir	Average annual accumulation
	Douglas-fir	Red alder		
Overstory	320	590	270	7.1
Understory	10	100	90	2.4
Forest floor	180	880	700	18.4
Soil	3 270	5 450	2 180	57.4
Total	3 780	7 020	3 240	85.3

Major differences in the pathways of elemental transfer in these eco- systems are also apparent (table 4). The annual elemental return by throughfall and litterfall is six to eight times greater in the case of al than in Douglas-fir. The annual uptake is three to five times greater. B comparing uptake with return (throughfall, litterfall) we can obtain some insight into the amount of annual increase occurring in the program for th two species. The comparison clearly shows that the Douglas-fir system sti has a net annual increase while alder has nearly reached a steady state be- tween uptake and return. This fact implies that alder has reached maturit and is nearly at the end of its rotation age while Douglas-fir is still growing. These results are consistent with the respective ages of the two stands and from what we know to be their life expectancy.

Loss of nutrients by leaching appears to be slightly greater under th alder ecosystem (table 4). Lysimeter collections of soil solution beneath the rooting zone have demonstrated that some increase in the leaching of nitrogen was found, in all probability because a greater amount of soil nitrogen is converted to the nitrate form in the presence of alder. Nitra to-ammonium ratios are strikingly different in the nitrate concentration o soil samples collected under the 38-year-old alder stand and an adjacent alder stand only 10 years old (table 5). For example, the ammonium-to-nit ratios shift from 0.01 or 1:100 at the age of 10 to 0.29 or 1:3 at the age of 38 years. In contrast, the ratio did not change for the Douglas-fir si but remained at 1:50 for both the 10-year-old and 48-year-old sites.

The period of time that nutrients remain within the forest floor and foliage is called *residence time*. In the case of Douglas-fir, this time i

Table 4--*Annual nutrient transfers in red alder and Douglas-fir ecosystems (kg/ha)*

Element/process	Douglas-fir	Red alder
Nitrogen		
Precipitation	1.1	1.7
Throughfall	1.5	8.8
Litterfall	13.6	111.1
Uptake	39.0	130.0
Leaching loss	0.6	2.2
Potassium		
Precipitation	0.8	2.2
Throughfall	10.7	12.4
Litterfall	2.7	67.0
Uptake	29.0	98.0
Leaching loss	0.02	No data
Calcium		
Precipitation	2.8	2.2
Throughfall	3.5	10.0
Litterfall	11.1	83.0
Uptake	24.0	116.0
Leaching loss	4.5	5.6

Table 5--*Soil ammonium and nitrate*[1/] *in two age classes, for Douglas-fir and red alder ecosystems*

Ecosystem	NH_4^+ PPM	NO_3^- PPM	NO_3^-/NH_4^+
Alder (age 10)	7.5 ± 2.6	0.10 ± 0.06	0.01
Douglas-fir (age 10)	6.8 ± 4.1	0.12 ± 0.04	0.02
Alder (age 38)	20.6 ± 2.6	5.90 ± 2.30	0.29
Douglas-fir (age 48)	1.9 ± 0.6	0.05	0.02

[1/] Samples collected and analyzed June 1976.

a)out 4 years, and translocation of nitrogen from alder to young foliage o̧curs at senescence. With alder, the residence period reflects translo-:tion of nitrogen from the leaf to the adjacent stem tissue before leaf fall (ig. 2). The residence time for nitrogen in the foliage of Douglas-fir is ɛtimated to be 6.5 years while that for alder was only 1.1 years. Resi-dnce time in the forest floor showed a similar trend with the nitrogen re-nining in the Douglas-fir site 10.2 years and 7.5 years in the alder site. Te residence time of nutrients in the forest floor was always greater than :e foliage except in the case of potassium at the Douglas-fir site. This ws probably because potassium is not part of the organic structure and radily leaches once the organic material is dead.

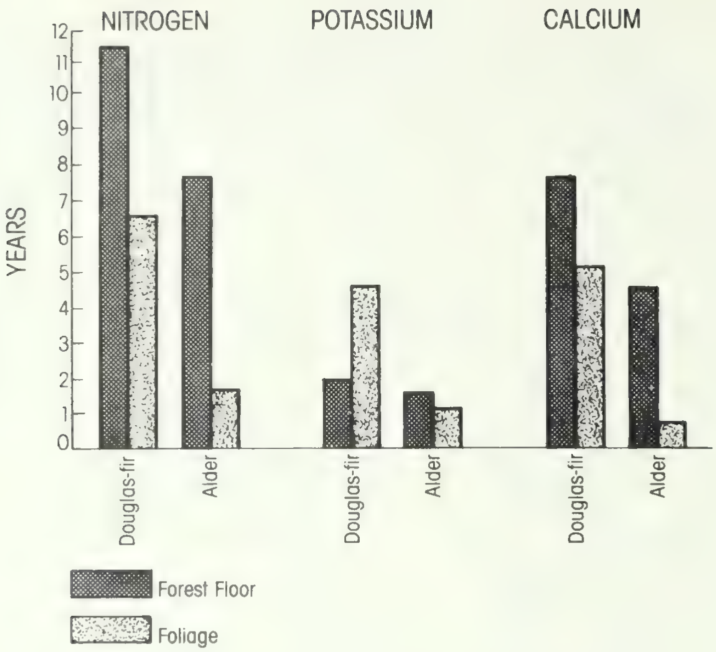

Figure 2.--Elemental residence time (yrs) in the foliage and forest floor of red alder and Douglas-fir ecosystems.

The tendency for the forest floor under red alder to decompose at a mo rapid rate than under Douglas-fir can be seen in figure 2 and is further confirmed from the decomposition data presented in table 6. When a standa decomposition bag technique was used,[2] the forest floor organic matter res idence time for alder was approximately one-third that of the Douglas-fir (table 6). This was caused more by the rapid rate at which the woody material under the alder decomposed than the rate at which the foliage its was broken down.

Table 6--*Organic matter decomposition and forest floor residence times for red alder and Douglas-fir ecosystems*[1/]

Ecosystem	Annual weight loss: Foliage	Annual weight loss: Woody material	Forest floor turnover period
	- - - - -Percent- - - - -		Years
Douglas-fir	46.5	5.7	9.1
Alder	55.1	12.9	3.7

[1/] Data supplied by Robert L. Edmonds, College of Forest Resources, University of Washington.

[2] Personal communication, Robert L. Edmonds, College of Forest Resources, Universit of Washington.

Conclusions

From comparative study of these two ecosystems, we can draw the following conclusions:

1. Elemental cycling is faster in the alder than in the Douglas-fir ecosystem--three to five times faster for uptake and six to eight times faster for return to the forest floor.

2. The alder forest appears to be reaching a steady state (difference between uptake and return) at age 38 while the Douglas-fir forest is still accumulating nutrients at age 48.

3. The red alder ecosystem is accumulating annually 85 kg/ha more nitrogen than is the Douglas-fir ecosystem, apparently because of biological fixation. The greater part of this accumulation is taking place in the soil and forest floor.

4. A greater percentage of nutrient elements is stored above the soil in the alder ecosystem, which could have a potential implication regarding nutrient loss due to harvesting of the stands.

5. Nutrients remain in the foliage and forest floor two to five times longer in Douglas-fir than in alder.

6. Nutrient leaching in the soil under the alder stand appears to be slightly greater than under Douglas-fir because we believe the rate of nitrification is greater in the alder soil.

There is a significant difference between the two species with regard to their mineral cycling properties. We believe that the differences carry considerable weight with regard to how the systems should be managed and the potential desirability of growing them as a mixed forest.

Results from this study clearly show the soil-improving attributes of red alder, especially in relationship to nitrogen supply. This characteristic assumes greater importance in forest management in Douglas-fir forests because of the repeated demonstration of nitrogen deficiency over a wide range of environmental conditions. The possibility of managing forest lands for capture of the nitrogen input of red alder to improve growth rate and wood production of Douglas-fir must be seriously considered. An economic value for this input can be roughly estimated by attaching a per-pound value to the added amount of nitrogen accumulating in these ecosystems and relating it to the cost of applying a similar amount of nitrogen by other means as reported elsewhere in this symposium.

Acknowledgments

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THE VALUE OF RED ALDER AS A SOURCE OF NITROGEN IN DOUGLAS-FIR/ALDER MIXED STANDS

WILLIAM A. ATKINSON, Associate Professor
College of Forest Resources
University of Washington
Seattle, Washington

WILLARD I. HAMILTON, Research Associate
Potlatch Corporation
Lewiston, Idaho

ABSTRACT

Numerous studies of forest fertilization have demonstrated that Douglas-fir stands in the Pacific Northwest and British Columbia grow better when fertilized with nitrogen. Since the long-term outlook for fertilizer supply and cost is uncertain, foresters should be examining alternatives for maintaining and increasing forest productivity. Several nitrogen-supplying species of plants exist, of which red alder is the most interesting. Alder not only imparts significant amounts of nitrogen to the forest soil, but also is a tree of increasing value for wood products.

This paper examines the economic value of alder both as a source of nitrogen and for its wood value. Three approaches are taken:

(1) An economic analysis is made of existing research plot data on the Wind River Experimental Forest. Results are contrasted with the alternative of artificial fertilization.

(2) Investigations of the nitrogen supplying capability of red alder reveal that relatively few alders are needed in order to supply Douglas-fir with its nitrogen needs.

(3) A general model is proposed for evaluating alder's place in Douglas-fir forest management. Data requirements are identified.

Introduction

This paper discusses the current use of nitrogen fertilizer in Douglas-fir management, presents a brief analysis of future nitrogen fertilizer

supplies, considers possibilities for adding nitrogen through biological means, provides a financial analysis of Douglas-fir/red alder mixed stand and, finally, conceptualizes a general model for evaluating red alder nit gen input to a forest system.

CURRENT USE OF NITROGEN FERTILIZER

The artificial fertilization of Douglas-fir stands in the northweste U.S. and British Columbia is one of the most intensive research areas in forestry (*1, 5*). Out of this effort has come one obvious conclusion: deficient nitrogen is the nutritional factor most limiting growth of Doug fir. Table 1 contains typical research results, and indicates that growt response to nitrogen is impressive.

As a result of impressive gains from nitrogen, along with large pric increases for logs and trees, the silvicultural practice of fertilizing t forest has grown to be an extremely large business, covering many hundred of thousands of acres. Annual cost of this activity will be close to $20 million by 1978. Barring a sharp rise in fertilizer cost, or a decline i wood value, operational forest fertilization of Douglas-fir can be expect to continue to increase at a fast rate.

Table 1--*Estimated mean response of 4-year gross total volume growth for Douglas-fir (percent above unfertilized control)*

Breast height age class (years)	Treatment (pounds of N per acre)	Site class			
		I	II	III	IV
		Percent			
10	200	11	23	--	--
	400	12	26	44	--
20	200	6	14	24	41
	400	7	15	28	--
30	200	6	13	23	40
	400	7	15	26	45
40	200	6	13	24	41
	400	7	15	27	47
50	200	6	14	25	43
	400	7	16	28	--

Source: Regional Forest Nutrition Research Project, University of Washington.

NITROGEN FERTILIZER SUPPLY

The principal fertilizer used in forest fertilization is urea, which contains 46 percent nitrogen. Urea is a combination of ammonia and carbo dioxide. Ammonia is made by combining hydrogen from a natural gas such a methane with nitrogen from the air (fig. 1). Since nitrogen comprises 78 percent of the air, the supply of this element is, for all practical purposes, unlimited. Hydrogen is the key to urea manufacture. Nitrogen is

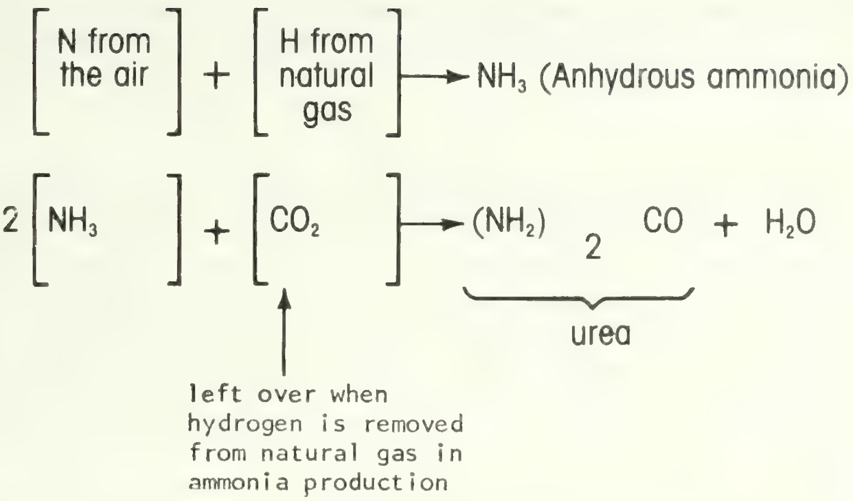


Figure 1.--Urea manufacturing process.

ptured from the air in the process of making ammonia, but it requires 3 ft^3 of hydrogen to capture 1 ft^3 of nitrogen (*10*).

In addition to natural gas, hydrogen can be obtained from other petro-leum derivatives, coal, wood chips, crop refuse, sewage sludge and, in fact, most any combustible material. Natural gas, however, is the feedstock for most all ammonia manufactured in North America; and it is being used up an alarming rate. Proven reserves are declining steadily.

As we approach the end of the century, North America may turn to coal fr its energy needs. In terms of availability, coal is the hydrocarbon th greatest potential for supplementing gas. Reserves of coal will last ndreds of years at current rates of use. At current levels of technology, wever, the manufacture of nitrogen fertilizers based on coal will cost -75 percent more than today's gas-derived fertilizers (*10*).

At best, though, coal is an interim answer. A coal-based economy would e up coal reserves relatively quickly, so that supplies that now appear equate for several hundred years might last considerably less.

It is also possible to use electricity to produce hydrogen, but this uld require large amounts of electricity to decompose water into hydrogen d oxygen. The only foreseeable means of producing such amounts of electri-ty at affordable costs are fast breeder nuclear reactors and fusion ocesses.

Other possibilities also exist for supplying hydrogen in the future, t the fact must be faced that supplies of nitrogen fertilizer, being

directly linked to energy production, are certainly not assured in the future at prices resembling those we have today. Fertilizers will probabl be available over the rotation of forests currently being planted, but the question is: "at what cost?" A truthful answer is that no one has any ide

NATURAL FERTILIZATION

With the preceding background, it is clear that foresters and farmers should be exploring other avenues than synthetic chemical fertilization fo maintaining and increasing productivity of their lands. Several possibilities exist. For example, legumes have the ability to supply their own nitrogen from the air and make it available to the crop. Another approach is through the use of blue-green algae, which can live on mineral elements carbon dioxide,and solar energy, and from this produce ammonia. Both snowbrush and bitterbrush, two common forest plants, also fix nitrogen in root nodules (*13*).

Foresters in the Douglas-fir Region also have a naturally growing tree species that not only imparts nitrogen into the soil, but also grows rapidly and produces valuable wood. This species is red alder. It has long been known that red alder bears root nodules that develop into cluste of considerable size (*7*). Atmospheric nitrogen has been shown to be fixed in these nodules. Nitrogen so produced is translocated to other parts of the plant (*2*).

Litterfall beneath alder stands is an important contributor of nitrog to the soil system. Red alder foliage has a much higher nitrogen content than does conifer foliage, and the amount of litterfall beneath alder stan greatly exceeds that of associated conifers (*6*).

Another major route of nitrogen from plant to soil is by direct excretion from living roots and nodules. It has been estimated that 60 percent of the soil nitrogen added in stands of red alder came from nodule excretions or free living micro-organisms (*15*).

Decomposition of dead roots and nodules is an obscure pathway for soi nitrogen enrichment by alder, and precipitation and fog-drip are additiona means by which the nitrogen of alder trees is conveyed to the soil. Nitro contents of both stemflow and leaf-wash are higher beneath alder stands tha conifer stands (*11*). Total annual contribution of available nitrogen to th soil by a fully stocked 38-year-old alder stand is in the neighborhood of 76 lbs per acre/yr (*3*). This represents a substantial contribution of nit gen to the system.

FINANCIAL ANALYSIS OF RED ALDER AS A SOURCE OF NITROGEN

Very little empirical data are available on the fertilizer effect obtained by growing red alder as part of a predominantly Douglas-fir stand. Several researchers have reported on what is considered to be the only existing example of a valid comparison between the growth and development

f a pure Douglas-fir stand and a mixed Douglas-fir/red alder stand (*8, 11, 2*). These stands are adjacent to each other and are located on the Wind iver Experimental Forest in southwestern Washington. Stand data are given n table 2.

Table 2--*Stand data - Wind River alder/Douglas-fir plots*[1/]

Species	Mixed stand	Pure stand
Douglas-fir seedlings planted (1928)	680/acre	680/acre
Red alder seedlings planted (1932)	1,210/acre	0
Douglas-fir volume in 1975 at age 47	27.00 CCF/acre	23.23 CCF/acre
Red alder volume in 1975 at age 43	19.41 CCF/acre	0
	46.41 CCF/acre	23.23 CCF/acre
Douglas-fir stems/acre in 1975[2/]	191	301
Red alder stems/acre in 1975[2/]	242	0
	433	301
Douglas-fir average tree size in 1975[2/]	14.1 ft^3	7.7 ft^3
Red alder average tree size in 1975[2/]	8.0 ft^3	0

[1/]Volumes are cubic volume to a 4-inch top.

[2/]5.5-inch d.b.h. and larger.

Which stand would you rather have? The mixed species stand is undoubt-edly the more valuable of the two, with a considerably higher volume and a larger tree size. These advantages, however, were obtained at the cost of planting 1,210 additional red alder trees per acre. Was this additional investment profitable? If the experiment were repeated, starting in 1977, would the mixed species stand still appear the better choice?

And, suppose we add a third alternative--fertilize the pure Douglas-fir stand at age 40. How does this approach compare in profitability to the other two alternatives? This latter alternative can be based on compa-rable data because, in fact, a fertilizer experiment was actually established in the pure Douglas-fir stand (*9*).

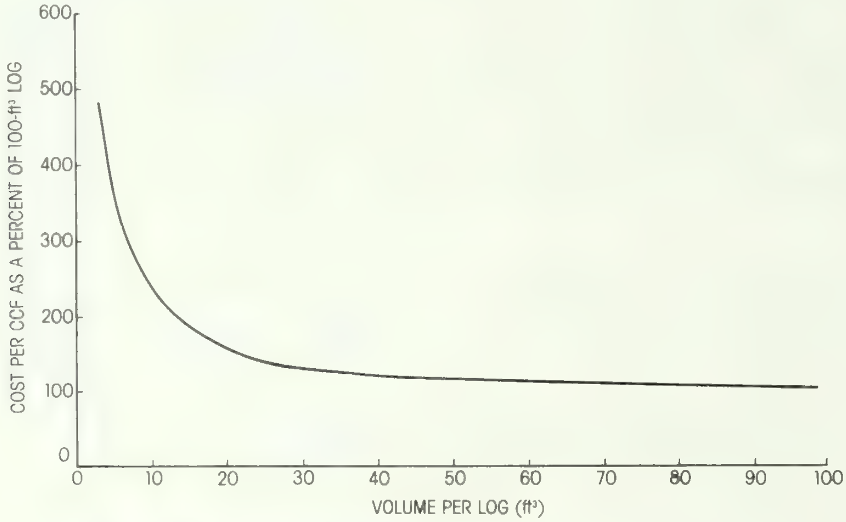
Hence, two questions will be examined:

1. If this experiment was repeated, starting in 1977, would the mixed species stand still appear to be the most profitable choice?

2. How do the mixed stand and pure stand alternatives compare in profitability with artificial fertilization of the pure stand?

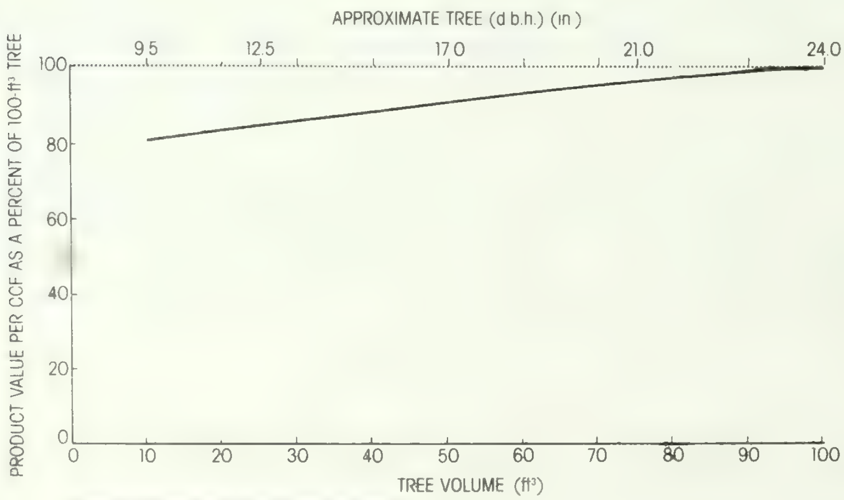
Before an attempt is made to value timber produced in this experiment, a assumption must be made regarding future stumpage prices. The best way

to do this is by examining the determinants of present stumpage price. Figure 2 illustrates the relationship between log size and harvest cost and indicates that small logs are much more expensive to handle than large logs. Not only are small logs and trees less valuable than large logs and trees because of harvest cost differences, but larger material also qualifies for higher and more valuable log grades and produces more lumber and less chip volume (fig. 3).



Source: T. C. Adams. Production rates in commercial thinning of young growth Douglas-fir. PNW-41, table 4

Figure 2.--Effect of log size on logging cost using a 60-hp. wheel skidder (percent of 100 ft^3 logs).



Based on data reported by Dobie, Kasper and Wright 1975. "Lumber and chip values from B.C. coast tree and log classes." B.C. Forest Products Lab

Figure 3.--Effect of tree size on product value of Douglas-fir.

Estimates of average 1977 stumpage prices for Douglas-fir and red alder re given in figure 4. Red alder stumpage is generally of considerably ower value than Douglas-fir because of higher logging costs and lower merchantable yield per acre. An examination of 1976 log prices in Washington[1] evealed that once alder logs appear at a log yard they are worth almost as uch as young-growth Douglas-fir. The problem is in the higher unit cost f moving alder out of the forest.

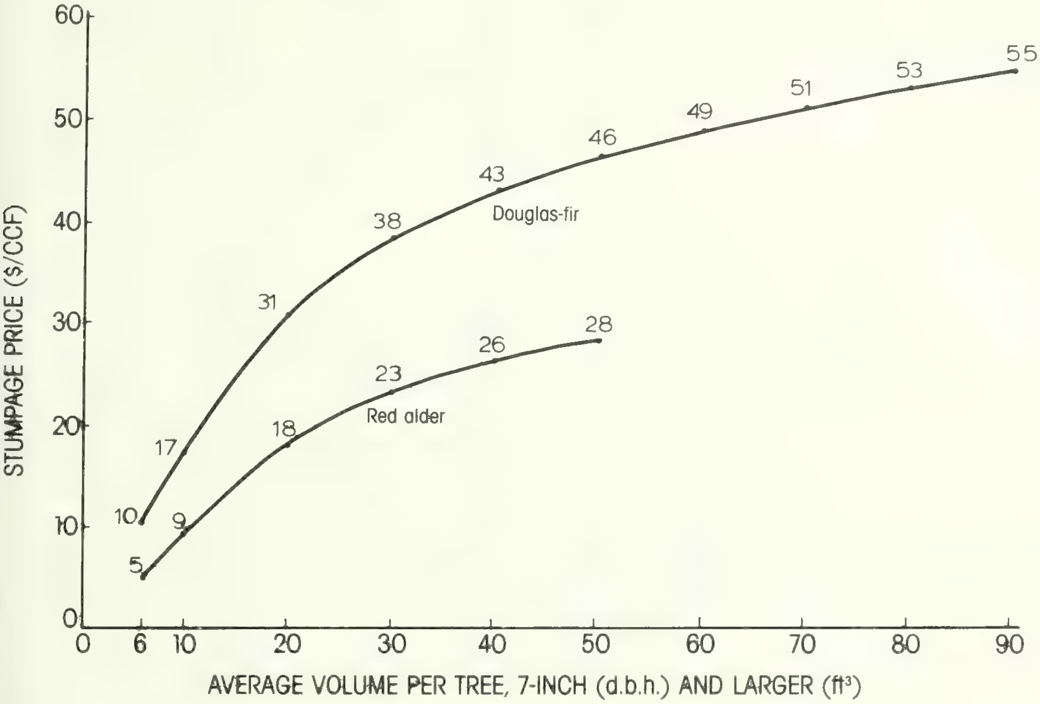


Figure 4.--Average stumpage prices by tree size for Douglas-fir and red alder (dollars per cunit).

Figure 4 is the starting point for future price estimates. It is sumed that the value relationship between tree sizes will remain unchanged r the next 47 years[2] and that all prices and costs, including fertilizer ts, will increase at an average "real" (i.e. inflation free) annual rate f 3 percent per year. Cost and value estimates, expressed in terms of 1977 llars, are presented in table 3. The three alternatives are shown in ematic form in figure 5.

Present net worth analysis was used to compare the three alternatives, sng a 6-percent "real" discount rate (table 4). The cost of interplanting h a high density of (1,210 trees per acre) of red alder trees causes the ied-species stand to be a less profitable alternative than artificial

[1]Data from monthly log price reports of the Department of Natural Resources, te of Washington.

[2]An investment period of 47 years is used because the Wind River experiments e last measured at age 47.

Table 3--*Estimated costs and values, Wind River alder/Douglas-fir plots*

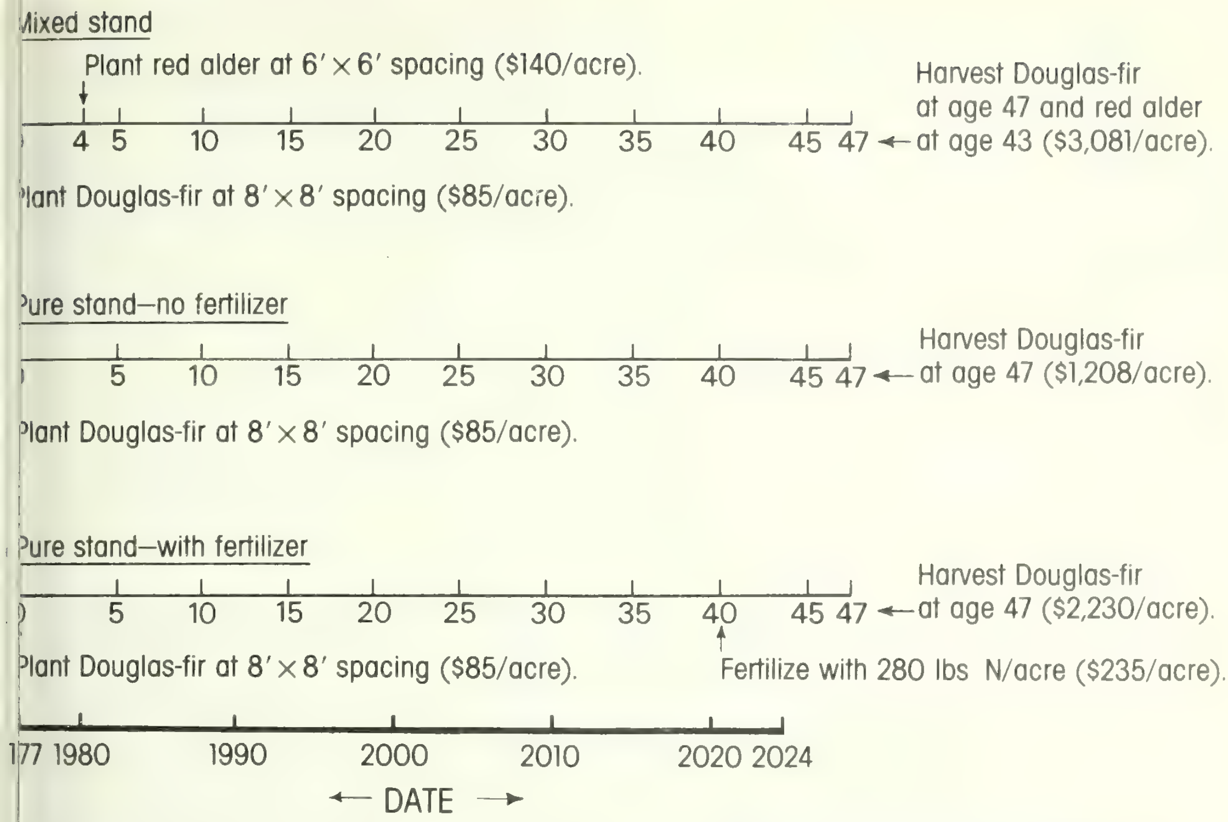
Species	Mixed stand	Pure stand, no fertilizer	Pure stand, with fertilizer
Douglas-fir volume[1/] - age 47	27.00 CCF/acre	23.23 CCF/acre	31.01 CCF/acre
Red alder volume - age 43	19.41 CCF/acre	0	0
Douglas-fir average tree size - age 47	14.1 ft^3	7.7 ft^3	10.3 ft^3
Red alder average tree size - age 43	8.0 ft^3	0	0
Estimated stumpage prices[2/] in 47 yrs:			
Douglas-fir	$94/CCF	$52/CCF	$72/CCF
Red alder	$28/CCF	0	0
Estimated stand value in 47 yrs:			
Douglas-fir	$2,538/acre	$1,208/acre	$2,230/acre
Red alder	543/acre	0	0
	$3,081/acre	$1,208/acre	$2,230/acre
Douglas-fir planting cost	$85/acre	$85/acre	$85/acre
Red alder planting cost in 4 yrs.	$140/acre	0	0
Fertilization cost in 40 yrs.	0	0	$235/acre

1/ Volumes are to a 4-inch top.

2/ Costs and values are in terms of 1977 dollars.

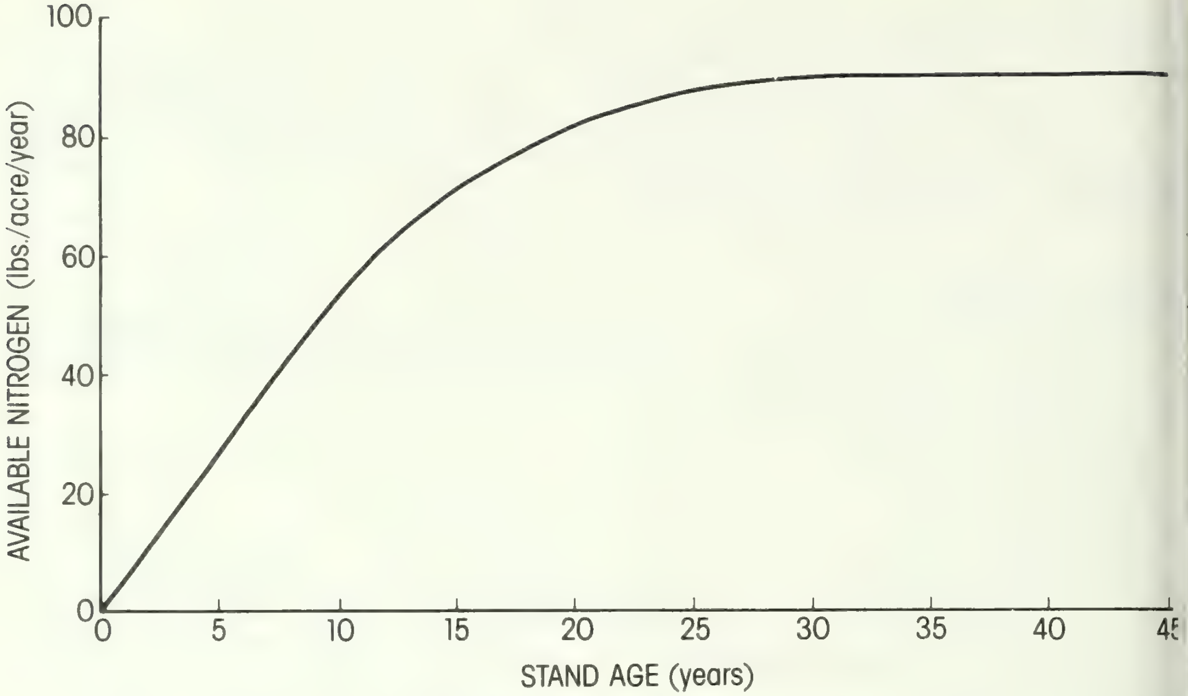
Table 4--*Present net worth of Wind River alder/Douglas-fir plots (assuming the study was repeated, starting in 1977)*

- - - - - - - - - - -6 percent discount rate- - - - - - - - - -	
Mixed stand, (present net worth)	≃ $ +3/acre
Pure stand, no fertilizer, (present net worth)	≃ $ -7/acre
Pure stand, with fertilizer, (present net worth)	≃ $ [illegible]



igure 5.--Three alternatives for Wind River plantations (values and costs in terms of constant 1977 dollars).

ertilizer. This conclusion, however, assumes that nitrogen fertilizer costs ncrease at the same rate as Douglas-fir stumpage prices (i.e. 3 percent per ear). Additional analysis revealed that if, in fact, nitrogen fertilizer osts increase at an annual rate of 5.4 percent (2.4 percent above the rate f increase for stumpage prices), red alder/Douglas-fir mixtures become inancially attractive, even with this high planting density. Since estiates of long-term cost increases for nitrogen fertilizers are pure speclation, it seems prudent for foresters to thoroughly investigate the rowth of red alder/Douglas-fir mixed plantations - or alternate rotations. uch information will be invaluable in the future.



Based on: Cole, Gessel, and Turner 1978

Figure 6.--Estimated red alder available nitrogen input per year (pounds/acre per year)(3).

ALDER STOCKING REQUIREMENTS FOR NITROGEN INPUT

The Wind River studies raise an important question: is it necessary to have such a high density of alder to provide adequate nitrogen for Douglas-fir? Perhaps 1,210 alder trees per acre are too many. In order t shed light on this question, we start with an investigation of the nitroge supplying capability of red alder stands. Figure 6 depicts estimates of available nitrogen[3] produced annually by a fully stocked alder stand at various ages (based on Cole, Gessel and Turner, 1978). Nitrogen inputs by an individual alder tree are estimated by dividing total stand input per acre by the number of trees found in a fully stocked acre (*14*). Results o this computation are presented in figure 7.

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[3]Available nitrogen is that portion of total soil nitrogen that can be readily absorbed by tree roots.

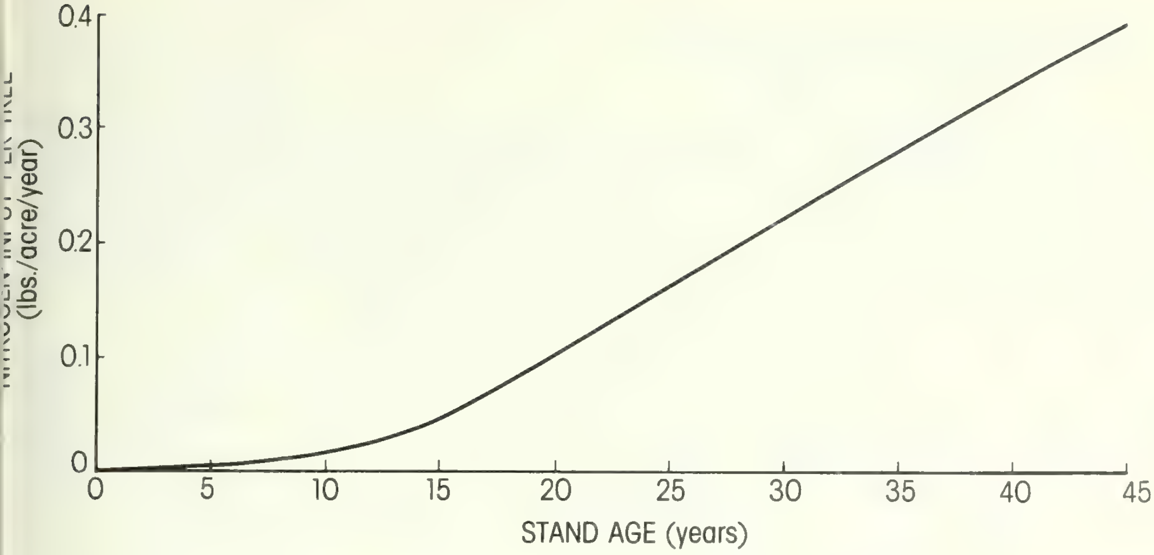

Figure 7.--Available nitrogen input by an individual red alder tree (pounds/acre per year).

Researchers feel that total annual nitrogen uptake in a fully stocked ng-growth Douglas-fir stand is approximately 35 lbs per acre (3). The stion under study, then, might be restated as: "How many red alder es are needed to produce 35 pounds of available nitrogen each year?" a from figure 7 can be used to answer this new question, with results in le 5. Based on this analysis, it appears that an initial planting density 200 alder trees per acre would provide, all by itself, sufficient nitrogen Douglas-fir after age 25. Most likely, far fewer alder trees would ually be needed as the Douglas-fir can obtain much of its nitrogen from t already in the soil.

Table 5--*Estimated number of red alder trees needed to produce 35 pounds of available nitrogen per year*

Stand age (years)	Trees needed
10	2,333
15	700
20	347
25	216
30	157
35	125
40	103
45	89

COST COMPARISON OF NITROGEN SUPPLIED BY ALDER AND BY ARTIFICIAL FERTILIZATION

Assume that 200 red alder trees are mixed into a Douglas-fir plantatio They all live until age 25, at which time alder mortality occurs at such a rate that sufficient alder trees survive to insure 35 pounds per acre per year of available nitrogen. By age 45, approximately 800 pounds per acre of available nitrogen will have been added to the system. If alder plantin cost is $35 per acre (for 200 trees), then the present value of direct monetary costs of nitrogen is 35/800 = $0.044 per pound.

It is also possible to provide 800 pounds of available nitrogen throug artificial fertilization. Assuming that all fertilizer nitrogen becomes available to the Douglas-fir, the required amount could be supplied by four treatments, each applying 200 pounds of nitrogen per acre. If treatments are made at stand ages 25, 30, 35 and 40, estimated present value (at 6 percent) of nitrogen fertilizer cost is $0.109 per pound, a quantity that is 2-1/2 times the cost of alder-supplied nitrogen.

One must hasten to point out that not all costs associated with using alder as a source of nitrogen are included in the previous analysis. Alder trees compete with the Douglas-fir for space, light, moisture, and nutrients To the extent that Douglas-fir contributes more usable wood and is valued at a higher stumpage price than red alder, the pure Douglas-fir stand will be more valuable than the mixed-species stand. A consideration of such value differences leads us to the final portion of this paper, a general model for evaluating alder/Douglas-fir mixed stands.

GENERAL MODEL FOR EVALUATING RED ALDER NITROGEN INPUT TO THE FOREST SYSTEM

As alder stocking is increased, nitrogen input is probably also increased, but less room is available for the more valuable Douglas-fir. How can one define an optimal combination of alder and Douglas-fir stocking over the life of the stand? A framework for evaluating this question is proposed in figure 8. The goal is to develop a flexible system that can be used to evaluate not only various combinations of Douglas-fir and alder stocking (including alternate rotations), but also artificial fertilizer use.

The general model of figure 8 is primarily useful at this state of our knowledge in defining data needs. These can be enumerated as follows:

1. Quantify red alder's available nitrogen input, both on a unit of stocking basis, and over time.
2. Define Douglas-fir response to a continuous supply of added nitrogen. Fertilizer research is now beginning to examine repeated treatments.
3. Define the competitive interaction between red alder and Douglas-fir in mixed-species plantations. We must be able to predict future yields and sizes under various stocking alternatives.

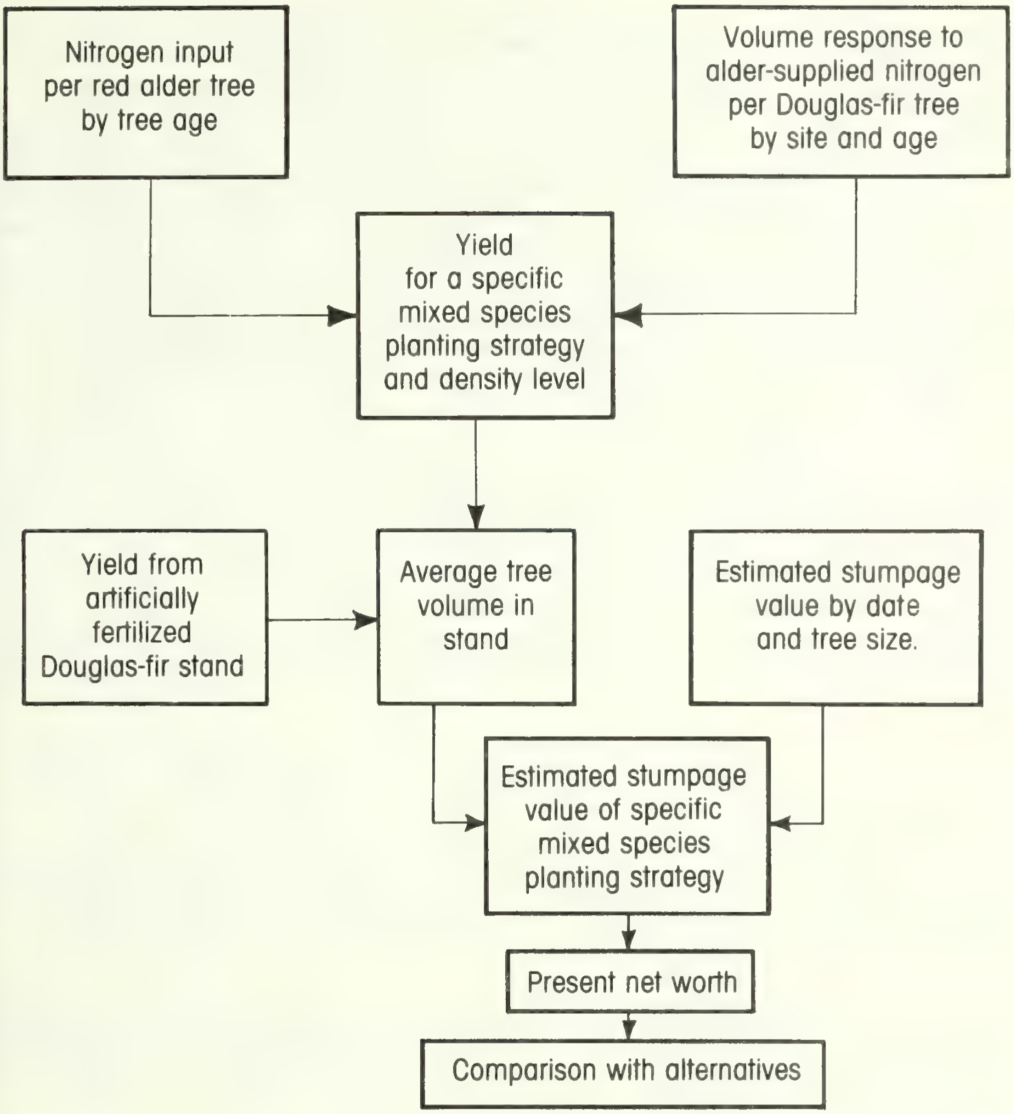

Figure 8.--General model for evaluating red alder nitrogen input to the forest system.

Conclusion

Based on what has been learned in the past few decades about the impact of nitrogen on Douglas-fir growth, it is certain that nitrogen addition will be a widely-used practice in managed stands of the future. Whether this addition will be through biological means or through the use of synthetic chemicals depends on future wood prices, as well as on future fertilizer costs. Nitrogen fertilizer is relatively inexpensive today and certainly offers the only practical avenue for increasing growth of existing stands. Its availability and cost in the years ahead, however, are uncertain. Should large cost increases occur, plantations that are currently being established may go through their entire rotation without the growth-stimulating effects of added nitrogen. Evidence already exists, as reported in this paper, that, in the absence of inexpensive chemical fertilizer, Douglas-fir plantations grown in mixture with red alder are of higher stumpage value than Douglas-fir pure species plantations. One might infer from this result that the only factor holding back current large-scale use of red alder as a nitrogen enricher is the existing low cost of urea fertilizer. This paper offers only tentative conclusions that are based on limited data, but the need for serious analysis of red alder's place in forestry should be clear to all. It is in the spirit of initiating such analysis that this paper is offered.

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TECHNIQUES AND COSTS OF CONVERTING HARDWOOD STANDS TO CONIFERS

ROBERT M. RANDALL, Economist
Pacific Northwest Forest and Range Experiment Station
USDA Forest Service
Portland, Oregon

ABSTRACT

The occupation by hardwoods and brush of large areas of the most highly productive coniferous timber growing sites is a vexing problem for foresters in the Douglas-fir region. The management of red alder is at the center of this problem. In general, management decisions have tended to favor removing hardwood-brush types and replacing them with conifer stocking.

Considerable work has been carried out in converting hardwood-brush sites to coniferous timber types. The major portion of this work has been done on industry lands in Washington. Several conversion techniques have been employed with varying degrees of success. Techniques used include harvesting, scarification, chemical spraying, and burning. A study of the costs and successes of applying these techniques shows that, while conversion projects are expensive, they are generally financially feasible if adequate stocking is obtained the first time. It is when the conversion process must be repeated that financial feasibility is in question.

Introduction

In this paper I will examine the practice of converting stands of hardwoods and brush to conifer stands. The basis for this practice is that under most circumstances conifers, especially Douglas-fir, are the more desirable tree species to have occupying a site. In examining stand conversion, I will focus on (a) a review of the extent and nature of the hardwood resource, (b) a description of conversion work accomplished to date and planned for the future, (c) a description of the costs and results of conversion techniques, and finally (d) a comment on the financial feasibility of conversion projects.

The Hardwood Resource

In the Douglas-fir region a serious obstacle to increasing the productivity of forests is the presence of hardwood cover on sites that are suitable for coniferous timber production. Table 1 shows that 12.8 percent of western Oregon's and 18.5 percent of western Washington's forest lands are occupied by hardwoods. Data from a report by Fight and Gedney (*4*) show that in western Oregon 84 percent of hardwood forests were growing on conifer sites, while in western Washington the figure is 79 percent (data did not include National Forests).

Table 1--*The proportion of hardwood forest acreage to total commercial forest acreage by major ownership classes in western Oregon and western Washington*

Ownership class	Total commercial forest acreage	Hardwood acreage	Percent of total for ownership	Percent of total hardwood acreage
		WESTERN OREGON[1/]		
National Forests	4,533,600	128,400	2.8	7.3
Bureau of Land Management	2,030,020	141,300	7.0	8.0
Other public	865,720	83,090	9.6	4.7
Forest industry	4,079,000	626,000	15.3	35.6
Other private	2,210,000	781,650	35.4	44.4
Total	13,718,340	1,760,440	12.8	100.0
		WESTERN WASHINGTON[2/]		
National Forests	2,365,000	35,000	1.5	1.9
State	1,223,000	148,000	12.1	8.0
Other public	458,000	86,000	18.8	4.7
Forest industry	3,634,000	713,000	19.6	38.6
Other private	2,296,000	864,000	37.6	46.8
Total	9.976,000	1,846,000	18.5	100.0

[1/] Beuter, John H., K. Norman Johnson, and H. Lynn Scheurman, 1976. Timber for Oregon's tomorrow. An analysis of reasonably possible occurrences. Oregon State University, Forest Research Lab. Res. Bull. No. 19, 111 p., illus. Corvallis, Oregon.

[2/] State of Washington, Dept. of Natural Resources. 1975. Washington forest productivity study--Phase 1 report. 156 p., illus. Olympia, Wash.

Hardwood forests are particularly extensive on industry and other private ownerships (table 1). In western Oregon 80 percent of hardwood forests are owned by industry and other private ownerships, while in wester Washington the figure is 85.4 percent (total hardwood forest acreage under

al ownerships). Hardwood forests are especially prevalent on lands classified as other private. In both States these ownerships have over one-third of their lands stocked with hardwoods. National Forest lands have a relatively small component of hardwood forests. This is due partly to past cutting practices but also to lower site productivity and lesser susceptibility to hardwood invasion.

Especially vexing to foresters is the fact that hardwoods tend to occupy the more productive timber growing sites. Data from the Beuter report indicates the following distribution of hardwood forests in Oregon by Douglas-fir site indexes (*5*).

Site index (productivity)	Acres	Percent
Greater than 165 (High)	861,520	48.9
120 to 165 (Medium)	569,560	32.4
50 to 119 (Low)	329,360	18.7
20 to 49 (Very low)	--	--
	1,760,440	100.0

These figures show 81.3 percent of hardwood forests occupying medium to high growing sites. Similar figures for hardwood forests in Washington (from unpublished Forest Survey data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.) indicate approximately 85 percent are on high and medium sites.

Red alder stands are an important component of the total hardwood resource in western Oregon and Washington. Red alder is the predominant hardwood species type in the Pacific Northwest. Metcalf (*6*) shows data indicating that red alder stands constitute 77 percent of hardwood forests in western Oregon and 87 percent of hardwood forests in western Washington.

Conversion of Hardwood Stands

As we have seen, the acreage of hardwood forests is substantial, is largely in private hands, and occupies some of the best timber growing sites in the Pacific Northwest. Because of the extensive hardwood component and the potential productivity of the lands it occupies, some landowners have decided to convert these stands into more productive conifer forests.

Table 2 is the result of a survey of hardwood and brush conversion practices in western Oregon and Washington (*3*).[1] The results are not entirely representative of hardwood conversion projects because brushland

[1]Readers interested in more information on hardwood-brush conversion and in the procedures used in obtaining the information presented in tables 2-4 of this paper should consult Dimock et al (*3*).

Table 2--*Area summary of high-site brush and hardwood lands as either converted or not yet converted to conifers for 16 ownership units in western Oregon and western Washington*

(In acres)

Ownership	Owned	Not yet converted			Converted							Hardwood not yet converted			
		Brush and hardwood	Brush	Hardwood	Total	Harvest	Tractor scarify	Multiple spray	Slash and burn	Spray and burn	High-lead scarify	To be converted	Retained in hardwoods	Retained and managed for harvest	Retained and not managed for harvest
Oregon	2,466,045	386,805	36,475	350,330	33,795	5,470	15,705	6,890	380	4,850	500	291,310	59,020	38,490	20,530
Washington	3,655,415	480,025	73,165	406,860	181,940	44,385	104,255	12,380	10,920	9,400	600	373,395	33,465	18,280	15,185
Total	6,121,460	866,830	109,640	757,190	215,735	49,855	119,960	19,270	11,300	14,250	1,100	664,705	92,485	56,770	35,715
Public	2,349,760	447,500	48,000	399,500	33,635	770	16,425	5,090	--	11,350	--	361,070	38,430	13,395	25,035
Private	3,771,700	419,330	61,640	357,690	182,100	49,085	103,535	14,180	11,300	2,900	1,100	303,635	54,055	43,375	10,680

1/ Dimock, Edward J., II, Enoch Bell, and Robert M. Randall. 1976. Converting brush and hardwoods to conifers on high sites in western Washington and Oregon--Progress, policy, success and costs. USDA For. Serv. Res. Pap. PNW-213, 16 p., illus. Pac. Northwest Forest and Range Experiment Station, Portland, Oregon.

oversion projects were also surveyed. The hardwood conversion projects, oever, were preponderant; and thus the results should provide a reasonable ude to the extent and nature of work being done.

The Federal, State, and private industry units surveyed manage 6,121,460 ces of commercial forest land in the Douglas-fir region. Of this total ceage, 12.4 percent is classified as hardwood type of which managers plan oconvert 88 percent to conifers. This leaves 12 percent that will either emanaged for hardwood timber production or will be retained for other uposes.

The total acreage converted in both States and all ownership classes a 215,735 acres. The preponderance of conversion work has been done in h State of Washington (84 percent) and in the private sector (84 percent). h large amount of conversion work done by private firms may reflect dif-eing management objectives between public and private owners, and it may lo reflect the much higher proportion of privately owned hardwood stands.

The survey classified conversion projects into six categories identi-id by the dominant site preparation technique employed. The proportion flands converted by these techniques is as follows:

Dominant site preparation techniques	Proportion of lands converted (percent)
Harvest	23
Tractor scarify	55
Multiple spray	9
Slash and burn	5
Spray and burn	7
High-lead scarify	1

Conversion Methods and Their Costs

The general sequence of events for each conversion project can be lssified into three major steps.

(1) Site preparation. Removing existing vegetation or scarifying the site to the extent that reforestation is possible.

(2) Regeneration. Planting the area with conifer seedlings.

(3) Post-regeneration treatments.

a. Animal damage control. Ranges from treating seedlings with repellants to individually caging a proportion of planted seedlings.

b. Plantation release. Typically involves spraying competing vegetation with a herbicide.

c. Replanting. Involves replanting if adequate stocking levels are not established by the first planting.

Table 3 shows the mean costs, cost ranges, and costs per established tree for the six classes of conversion treatments surveyed.[2] The costs ar identified by the dominant site preparation treatment used on a project; b the costs actually represent expenditures for all activities, in all three major steps, occurring up to the establishment of a conifer stand. To bet understand just where the costs do occur in a project, it is useful to loo at the three conversion stages individually.

TABLE 3 -- *Costs of conversion by technique, expressed in 1975 dollars per acre based on 99 projects in western Oregon and western Washington*[1/]

Technique	Mean cost	Cost range	Cost per established conifer	Number of projects represented
Harvest	103	41-197	.39	13
Tractor scarify	140	45-487	.45	52
Multiple spray	149	39-351	1.15	19
Slash and burn	235	170-300	.52	6
Spray and burn	269	135-505	.57	8
High-lead scarify	210	--	.86	1

[1/] Dimock, Edward J. II, Enoch Bell, and Robert M. Randall. 1976. Converting brush and hardwoods to conifers on high sites in western Washington and Oregon--Progress, policy, success and costs. USDA For. Serv. Res. Pap. PNW-213, 16 p., illus. Pac. Northwest Forest and Range Experiment Station, Portland, Oregon.

Site Preparation Costs

Site preparation methods often comprised various combinations of harvesting, slashing, scarification, chemical application, and burning. Fo example, combinations such as harvesting and scarification often occurred on the same project. In such cases the dominant method was used to classif the project.

HARVESTING

When merchantable material is present, harvesting can reduce or eliminate site preparation costs. Harvesting was the predominant means

[2] To establish comparability of cost data occurring at different times, all data were adjusted for inflation and compared at 1975 price levels.

of site preparation in 13 projects; and except for 2 projects that used some tractor scarification ("crushing"), there was minimum use of machinery in site preparation.

TRACTOR SCARIFICATION

Scarification, in conversion projects, generally entails the uprooting, windrowing or piling, and perhaps burning of unmerchantable hardwoods and brush. The average cost of tractor scarification was $55 per acre. Of 52 scarification projects, 17 included some harvesting of merchantable timber. The median cost for scarification was $45 per acre with about 70 percent of the costs falling between $25 to $65 per acre. Tractor scarification was generally limited to lands with slopes not exceeding 30 percent.

MULTIPLE SPRAYS

Multiple spraying involves the repeated application of herbicides until unwanted vegetation is dead or at least until it represents little threat to coniferous plantings. Spraying can occur before and after planting of conifer stock. The cost of spray projects largely depends on the number of sprays applied. Sprays applied from two to four times seemed common practice. Sprays were generally applied from a year to several years apart depending on circumstances. For 19 observations the median single application spray cost was $12.77 per acre while the average cost was $13.18 per acre. Only three observations fell outside the range $12 to $14.90 per acre.

Most multiple spray projects took place on slopes ranging from 30 up to 100 percent.

SLASH AND BURN

This technique involves felling all unmerchantable trees, using an herbicide or desiccant on understory vegetation, and burning. Based on only a few observations, slashing costs between $60 to $75 per acre while broadcast burning costs from $30 to $55 per acre.

SPRAY AND BURN

This technique involves the treatment with herbicides of hardwoods and brush often in conjunction with a harvest of a merchantable overstory. Broadcast burning follows. With only a few observations, costs ranged from $121 to $213 per acre with values skewed toward the lower end of the range.

HIGHLEAD SCARIFICATION

This technique involves scarification by cable yarding with heavy weights. There was only one example of this relatively experimental method. Costs were $118 per acre on a 50-percent slope.

Regeneration Costs

Hand planting is the predominant regeneration method used in the Douglas-fir region. We found a wide range in planting costs per tree. Th range was from \$.05 to \$.22 per tree with the median cost of planting with 2-0 stock being \$.11 while the median cost with 2-1 stock was \$.13. One can determine per acre costs for a particular project by multiplying cost per tree by number of trees planted. For example, a project with 600 trees per acre would cost about \$66 per acre for 2-0 stock and about \$78 per acr for 2-1 stock.

Postregeneration Treatment Costs

Costs are often incurred after the regeneration stage. These costs m be required to protect the investment from animal damage or from competing vegetation. Likewise it may be necessary to replant all or part of a proj- ect because of the failure of planting stock to survive. Of the 99 projec reported here, 82 had incurred some additional costs after the initial regeneration.

In all, 70 projects used some form of animal damage control. Costs ranged from lows of \$.50 per acre for the use of rabbit repellants on seed- lings to \$120 per acre for wire-caged seedlings. Of the 70 projects, 47 had costs of \$1 or less per acre, 15 projects cost from \$2 to \$30 per acre and 8 projects cost in excess of \$30 per acre.

Release of plantations from competing vegetation was carried out on 4 projects. Six of the projects cost less than \$10 per acre, 18 projects co from \$10 to \$20, 11 projects from \$21 to \$40, and 6 projects cost over \$40 per acre.

Replanting was necessary on 24 projects. Costs varied widely. The average cost was \$62 per acre with 15 of the projects falling in the range \$32 to \$92.

Conversion projects often required combinations of the above postregen- eration treatments. Costs of these combinations ranged up to \$200+. Of th 39 projects combining two or more treatments, 21 cost less than \$50, 9 cost between \$50 and \$100, 6 cost between \$100 and \$200, and 3 cost more than \$200 per acre.

Treatment Success

At least for the short run, the success of conversion projects is measured by the level of stocking obtained. Table 4 shows the levels of stocking obtained for 99 projects. Stocking percent was based on the stock-quadrant method with 100 1/250-acre plots per project. Estimates of density were based on the measured distances from 25 sampling points to the nearest established conifer.

TABLE 4 -- *Number of projects by conversion technique achieving given stocking levels for 99 projects in western Oregon and western Washington. Numbers in parenthesis indicate projects that were replanted*

(Number of projects)

Stocking level	Harvest	Tractor scarify	Multiple spray	Slash and burn	Spray and burn	High-lead scarify	Total
Nonstocked 0- 9 percent	0	0	1	0	0	0	1
Low 10- 39 percent	1	7(2)	4	0	0	0	12(2)
Medium 40- 69 percent	9(3)	19(3)	14(2)	2(2)	2	0	46(10)
High 70-100 percent	3(2)	26(3)	0	4(1)	6(4)	1(1)	40(11)
Total projects	13(5)	52(8)	19(2)	6(3)	8(4)	1(1)	99(23)
Mean stocking percent	61	65	44	77	80	71	
Stocking range	39-79	10-95	6-69	52-93	64-91	--	
Mean density trees per acre	265	310	130	453	424	244	

Table 4 shows that out of a total of 99 projects, 86 were medium stocked or better. In 12 cases (shown in parenthesis) even replanting failed to result in high stocking. The methods, utilizing burning, produced the greatest measure of success in that 10 of 14 projects resulted in a high stocking level. Tractor scarification produced high stocking 50 percent of the time. The most disappointing results came from the use of herbicide sprays as the primary method of site preparation. Multiple spraying failed to produce stocking levels over 70 percent.

Conclusions

As we have seen, hardwood and brush conversion projects are not cheap. Complicating matters is the fact that results in the form of adequate stocking levels are far from sure. It is not reassuring to see that well over half the projects result in stands less than 70 percent stocked (table 4). Many such lightly stocked stands may not be of sufficient density to produce income opportunities through commercial thinning when they reach merchantable size. Further, the present net values of future returns from such stands may not be sufficient to offset costs.

What of stands that are over 70 percent stocked? Are the costs of conversion projects justified by future returns? From Beuter and Handy's (*1*) economic guidelines for reforestation a number of tables show expected returns for various management situations. Using table 42, representing Douglas-fir site II, we can determine expected returns for a management regime of frequent light commercial thinnings preceded by a precommercial thinning and assumptions of no taxes and constant prices. At 5-percent discount rate for a financially optimum rotation, the return would be $852 for site II. At a 7-percent discount rate, the present net worth for site II would be $581.

From table 3 we can see that the mean costs of the most expensive conversion technique was $269. The highest cost project was $505 per acre. At 5 and 7 percent, we could expect to more than break even, if we achieve high stocking levels. Of course, the financial feasibility of conversion projects will vary by the owner's situation, by site, and by factors outside the owner's control such as interest rates and stumpage prices. Nevertheless, conversion projects do look profitable on sites I and II under a wide range of ownership situations under current market conditions. What seems crucial is the level of stocking obtained and the costs required to obtain a high level of stocking. It would seem prudent for managers to put extra effort into insuring successful regeneration on the first planting.

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SHOULD ALDER BE REPLACED BY CONIFERS?

THOMAS R. WAGGENER, Associate Professor of Forest Economics
College of Forest Resources
University of Washington
Seattle, Washington

ABSTRACT

As with most hypothetical questions, the question of whether alder should or should not be replaced with conifer must be answered ambiguously. It is assumed that this basic question will be approached from an economic or financial point of view.

Application of financial analysis to the question of site conversion requires two basic sets of information: 1) biological response data relevant to the management options to be considered, and 2) present and future values for both costs and returns for each management option, including the relevant cost of capital.

A primary consideration in the analysis of site conversion is the determination of yield responses from management. Also, projected time trends in both yield values and costs need to be carefully considered, since both management feasibility and the comparative advantage of an optimal management program can change greatly under such trends. Because of the long financial production periods, the cost of time is often a major determinant of economic feasibility.

Examples for generalized site conversion analysis are reviewed and the implications of the major management variables are discussed. The application of these approaches requires each manager to carefully assess the specifics of his forest land and the site-specific cost and value relationships.

Introduction

Recent years have shown a substantial growth in interest in the relative merits of producing red alder as a commercial species on substantial acreages of forest land in the Pacific Northwest. In part, this interest is spurred by the naturally occurring stands of alder that have simply grown in spite of any conscious management effort. These stands are frequently seen as a problem, since conventional wisdom says that conifers are preferred and that otherwise productive sites are being underutilized when occupied by alder. Hence, we are faced with the question: Should

alder be replaced by conifers? as with most hypothetical questions, this question must be answered ambiguously: It all depends. There is simply no rational basis for prescribing management nostrums as generalized land management guidelines.

The question of replacing alder with conifers is essentially one of economics - or at least it will be assumed to be one of economics for the purposes of this discussion. That is, it is assumed that we are interested in using our forest lands efficiently from an economic point of view. This requires us to set two conditions as limits on our analysis. First, we want to avoid taking management actions that are not economically feasible - tha is, the anticipated costs exceed the anticipated returns when properly adjusted for time. Second, when faced with mutually exclusive alternatives which are technically and economically feasible, we want to choose the alternative that contributes the most to our economic objective. When only one alternative is feasible, no choice is implied. More typically, however, we must choose the preferred course of action.

For the purposes of discussion, we will simply assume the goal of our forester-decisionmaker to be the maximization over time of anticipated net value from his timber production efforts. As such, the criterion of maximum net present value is taken as the proper decision variable. Conventional tools of financial analysis will help us outline the dimensions of our problem.

Our original question implies that we have existing stands of alder and that the issue at the moment is whether to harvest those stands (commerciall or otherwise) and replace them with conifers. Basically this involves two separate but related issues: whether to harvest the alder and whether to follow up such harvesting with the establishment of conifers. Alder could b harvested and the land again planted with alder, allowed to remain fallow, o converted to a nontimber use. On the other hand, the existing stand of alde can be retained for some yet undetermined period of time. Financially, our decisionmaker will want to optimize the combined results of these two decisi To hold the existing stand delays the time at which conifers (or another ald stand, or an alternative nontimber land use) can be established. If the alternative use has a positive value (is economically feasible), such a dela will entail a cost. In return, the existing stand may result in an increase value. For operational reasons, we would simply want to hold the existing stand only so long as the increase in value more than compensates us for the costs of delay. In practice this is not as easily determined as it might appear. We need to carefully formulate our methodology so that the final results tell us what we want to know. A precise answer to the wrong question is of little value and can even be detrimental.

Methodology

The application of financial analysis to the question of timber site conversion requires two basic sets of information: a) biological response data relevant to the species and the management options to be considered,

ad b) present and future values (estimates) for both costs and returns for ach management option, including the relevant cost of capital.

The first priority is to determine the economic feasibility of manage-ent for both retention of red alder and potential management of the site or conifer. In effect, we want to be assured that the options we are con-dering are really feasible, on their own merits, before attempting to re-olve the choice between the two.

Let's consider the red alder option first. It is tempting to look at ne existing stand and to formulate our question of conversion around the ondition of this stand. This, however, is not really our best option. Al-nough we are constrained by the existing stand (at the moment), our real otions are for future management for either alder or conifer. Needless to ay, we should determine the most profitable form of management for alder if any) as the basis for our assumed future management. It does no good to onstruct an analysis based on any form of management or rotation age other nan the best.

Likewise, we must identify the best form of management which is likely f the site is converted to conifer. This again means that we must deter-ine the optimal intensity of management and rotation for the particular pecies and site. It should be apparent that the analysis of alder and con-fer requires us to specify site equivalents for the two species. Although t is not within the scope of this paper to examine the topic of site equiv-lents, suffice it to say that this is an area where much more specific data re needed. Unless we know the alder and conifer potential for the same iece of land, there is no way that we can formulate a meaningful economic nalysis of the conversion question. More on this point later.

The above-mentioned analysis of best management for alder and conifer ill lead us to the answer to site conversion - if the analysis has been roperly done. The form of future management with the highest positive net resent value, determined at the proper cost of capital, is our best longrun ption. This does not, however, automatically tell us what to do with our xisting stand. It is necessary to consider the condition of the existing tand relative to the feasibility of timing of conversion to conifer or the e-establishment of the same species. There *may* be some future period for hich it is financially feasible to hold the existing stand, even at the ost of delaying future management for either alder or conifer.

The suggested economic methodology can be summarized as follows:

1) determination of site comparison and alternative production/yield functions for red alder and conifer management,

2) evaluation of the economic feasibility of management options for each species and determination of present value of optimal future management regimes,

3) analysis of present stand value and future management costs if held, and

4) analysis of the economic advantage/disadvantage of site conversion either now or some time in the future.

The mechanics of such an analysis have been described elsewhere (*2, 3*). A graphic representation of this process is reproduced as figure 1. The financial calculations for a sample analysis are contained in appendix 1.

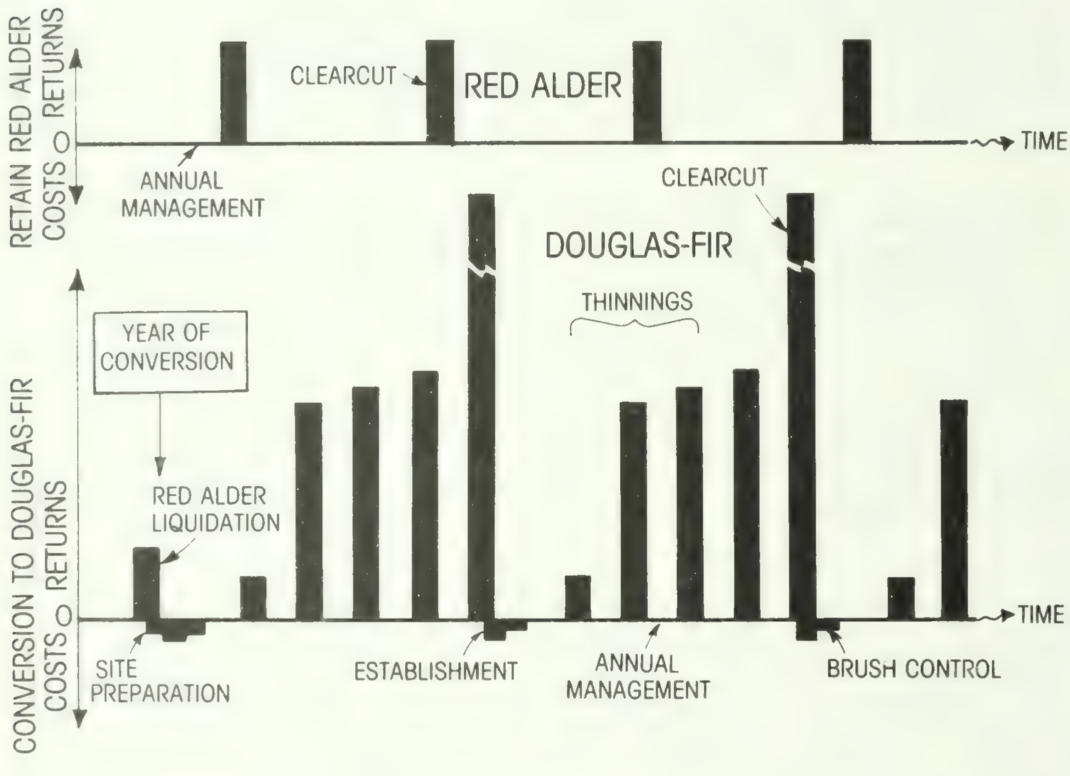

Figure 1.--Representative costs and returns to be expected from retaining red alder and from liquidating red alder and converting site to Douglas-fir, Yoho, et al. (3).

The upper portion of figure 1 illustrates the consideration of retaining red alder. Our manager is faced with determining the present value of a perpetual series of red alder yields, properly adjusted to account for the age of the present stand. This requires us to determine the present value of the existing stand, which is to be harvested at the end of the holding

eriod, and the present value of all subsequent stand values derived at the nd of all future rotations. These combined values, then, represent the resent value of total revenues to be obtained from retention of alder.

Likewise, the upper portion of figure 1 indicates certain annual manage- ent costs, which must be paid during both the holding period for the exist- ng stand as well as during future rotations; assuming retention of alder. hen both revenues and costs are discounted, we have the present value of etaining alder. It should be noted that figure 1 assumes that both the ex- sting stand and future stands will be harvested at a predetermined rotation. n practice, we would want to carefully determine the future rotation and he proper year of harvest of the existing stand (holding).

The lower portion of figure 1 illustrates the more complex case of site onversion to conifer. In considering revenues, we first see that the liqui- ation of the existing alder stand will result in an immediate receipt at he time of conversion. Second, for the conifer regime illustrated, there re receipts from both thinnings and final harvest, which reoccur at regular ntervals for all future conifer rotations. Finally, conversion involves one-time site preparation cost at the time of conversion, as well as fu- ure stand establishment, brush control, and annual management costs. All ut the site preparation cost are assumed to repeat at regular intervals for all future rotations.

Illustrative Analysis

The particular numbers and assumptions used in an illustrative example re not as important as a logical and consistent approach for the analysis. Each landowner clearly faces a different set of management options and mar- ket conditions, and it would be foolish to attempt to present site-specific findings. Nevertheless, the results presented by Yoho, et al. (*3*), can be instructive with respect to the methodology used. Specifically, it is use- ful to examine the consequences of possible misspecification of site equiv- alents between red alder and conifer. This comparison is reproduced as table 1.

The upper portion of table 1 represents the situation where we have mistakenly equated the alder site with too low a conifer site equivalent. We have thus understated the relative productivity of the site for conifer. The original (faulty) analysis indicated that alder should be retained under certain conditions. Thus, at a 3-percent discount rate, alder would be re- tained only where conversion costs were high. At 6 percent, alder would be retained for both high and medium conversion costs, and for low conversion costs for stands 55 years of age or older. At 9 percent, alder would be re- tained for both high and medium conversion costs, and again for 55-year-old stands (or older) with low conversion costs.

With correct site equivalence, however, we see that at 3 percent our finding of retention of alder under high conversion costs is reversed. Likewise, the retention of alder at 6 percent for stands 55 years of age and

Table 1--Conversion recommendations that would be changed if the estimated productivity of Douglas-fir on a given red alder site were changed[1]

(Number of years to wait[2])

Red alder/ Douglas-fir site class	Present age (years) of red alder stand	Guiding rate of return								
		3 percent			6 percent			9 percent		
		High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs
		If a red alder site 70 is actually a Douglas-fir site III rather than IV, the shaded R's should be numbers--convert to Douglas-fir								
70/IV	15	R	20	0	R	R	20	R	R	20
	25	R	10	0	R	R	10	R	R	10
	35	R	0	0	R	R	0	R	R	0
	45	R	0	0	R	R	0	R	R	0
	55	R	0	0	R	R	R	R	R	R
	65	R	0	0	R	R	R	R	R	R
		If a red alder site 90 is actually a Douglas-fir site IV rather than III, the shaded numbers should be R's--do not convert to Douglas-fir								
90/III	15	20	0	0	R	20	10	R	R	20
	25	10	10	0	R	10	0	R	R	10
	35	0	0	0	R	0	0	R	R	0
	45	0	0	0	R	R	0	R	R	0
	55	0	0	0	R	R	0	R	R	R

NOTE: Shaded recommendations would be reversed if an error were made in estimation of Douglas-fir site productivity.

1/ Table entries were extracted from table 7; conversion cost levels are defined in table 4; the high management costs and low prices are defined in table 6 of (3).

2/ Before conversion of red alder to Douglas-fir. An "R" means that red alder should be managed in perpetuity.

Source: Yoho, Chappelle, and Schweitzer, 1969, table 10, p. 18.

der is also reversed. Our site misspecification would result in overre-ntion of alder.

One could err, of course, in the other direction. The lower portion of ble 1 illustrates the consequences of overstating the conifer productivity lative to alder. Without detailing the results, it is apparent that con-rsion would be recommended too frequently. As is evident in both portions table 1, conversion becomes increasingly less desirable at higher interest tes, particularly when conversion costs are medium to high. This is in rt attributable to the longer rotation for conifer (hence longer invest-nt period) as well as the fact that conifer management is assumed to re-ire both stand establishment and brush control costs which must also be rried over time. Needless to say, conversion doesn't necessarily always y.

Factors Affecting Site Conversion Decisions

A primary consideration in the anlaysis of site conversion is the de-ermination of yield responses from management. This includes dimensions both quality and quantity. From the quality standpoint, stumpage prices an and do vary greatly based on log size and quality. One should be wary f analyses utilizing average stumpage prices without due recognition of uality differentials. The importance of yield volume is partly revealed n the previous discussion of site comparison. A higher site generally means greater recoverable volume and/or higher quality logs at a given age. More olume means a greater economic yield. Economic feasibility is quite sensi-ive to yield volumes and the per-unit values attached to future yields. ince yield values are also sensitive to quality measures, accurate quality-ield relationships are critical.

In addition to volume yields, projected time trends in both yield values nd costs need to be carefully considered, since both management feasibilty nd the comparative advantage of an optimal management program can change reatly in response to such trends. Finally, a careful consideration of the ost of capital is required. Because of the long financial production peri-ds, the cost of time is often a major determinant of economic feasibility. he use of artificially low discount rates to justify otherwise unprofitable anagement regimes is questionable at best.

Examples of Hardwood and Conifer Stand Analysis

Does hardwood management pay? Does conifer management pay? Should we onvert? When? These are all good questions asked daily by forest managers. nfortunately, few pertinent answers can be given. Nevertheless, it can be seful to examine some recent indicators of economic feasibility for both onifer and hardwood production and draw some inferences about the potential or conversion. The examples which follow are taken from the recent study y the Washington Department of Natural Resources analysis of timber produc-ivity (*1*). Following our earlier suggested methodology, we will summarize

first the findings with regard to the economics of hardwood production, the look at the feasibility of conifer production, and finally make some comparisons between the relative feasibility of the two.

HARDWOODS

The Department of Natural Resources examined potential management of hardwoods on the approximate 1.8 million acres currently occupied by hardwoods in western Washington. About 1.4 million acres were considered "hardwoods on conifer site" with the remaining 0.4 million acres classed as "hardwoods on hardwood site." The distinction in site was based on both the hardwood index as well as assumptions about conifer productivity. Hardwood site index 70 to 90 was considered "hardwood on conifer" while hardwood site index 100 to 120 was considered "hardwood on hardwood site." Assuming natural management yields, average 1976 costs, 1976 hardwood log values, and a range of interest rates (real rates after taxes), the study concluded that economic management opportunities for hardwoods (i.e. red alder) were extremely limited.

For "hardwood on conifer sites" (the lower alder sites), natural management resulted in negative land values for all hardwood rotations at both 5- and 7-percent discount rates with constant costs and price assumptions. Similarly, if both costs and prices were allowed to increase at an annual rate of 2 percent, all land values remained negative. When costs were held constant, while prices were increased by 2 percent per year, management of forest industry lands on site 90 became marginally feasible at a 5-percent discount rate; all other options continued to show negative returns.

The situation was slightly better for "hardwood on hardwood sites" - but not much better. No management showed positive returns under the assumption of constant prices and costs. With a 2-percent increase in both prices and costs, management of publicly owned site 90 lands became feasible only at a 5-percent discount rate as did all "hardwood on hardwood sites" in forest industry ownership. Nonindustrial private ownership continued to show negative returns under this price-cost assumption.

With an assumed 2-percent increase in prices, at constant costs, hardwood management on these better sites (site index 100-120) became feasible for all ownerships but only at the modest 5-percent discount rate. At 7 percent, management was again uniformly submarginal.

We should remember that these conclusions are conditional on the assumed yields, prices, and costs. Nevertheless, the pattern of results indicate that even under the most favorable circumstances of increasing prices and constant costs, hardwood management is questionable on all but the better hardwood sites even at modest interest rates.

CONIFERS

Does the above view of hardwood management necessarily mean that conifer management should prevail? Obviously not. Our methodology specified that we

ut also examine the economic feasibility of conifer management before making any relative comparisons. Table 2, reproduced below from the DNR study,

Table 2--*Conifer investment recommendation summary based on the L.E.V. solutions, by owner group, price and cost combination, site, and interest rate*

Owner	Price and cost combination	Site					
		High		Medium		Low	
		Real interest rate (percent)		Real interest rate (percent)		Real interest rate (percent)	
		5	7	5	7	5	7
Public	Constant prices and costs	X[1]	0[2]	X	0	0	0
	Two percent rate of increase in prices and costs	X	X	X	X	X	0
	Two percent rate of increase in prices with constant costs	X	X	X	X	X	X[3]
Forest Industry	Constant prices and costs	X	0	X	0	0	0
	Two percent rate of increase in prices and costs	X	X	X	X	X	0
	Two percent rate of increase in prices with constant costs	X	X	X	X	X	X
Other Private	Constant prices and costs	X	0	X	0	0	0
	Two percent rate of increase in prices and costs	X	X	X	X	X	0
	Two percent rate of increase in prices with constant costs	X	X	X	X	X	X[3]

[1] The symbol "X" indicates a positive Land Expectation Value.

[2] The symbol "0" indicates a zero or negative Land Expectation Value.

[3] These only include 90 percent of the acres. Ten percent of the acres were considered for regimes without thinning, but all the L.E.V.'s were negative.

Source: Washington Department of Natural Resources. Forest Productivity Study, Phase II.

summarizes the findings with respect to conifer management. The X designation in the table represents management options where positive land values were obtained, indicating economic feasibility under the stated conditions. The 0 designation indicates that no management was economically feasible under the stated conditions. Examination of table 2 shows an interesting pattern. For example, conifer management for all ownerships and all cost-price assumptions show positive returns for high and medium sites with the sole exception of the constant cost/price assumption at a 7-percent discount rate. The situation is less favorable, however, for low site lands. Perhaps not surprisingly, no ownership shows positive value for any management regime for low sites under constant price/cost assumptions at either 5- or 7-percent real discount rates. With an assumed 2-percent trend in both costs and prices, management pays its way at 5-percent discount rate but not at 7 percent. Finally, with constant costs but an increasing price trend, conifer management shows positive returns at both 5 percent and 7 percent.

The Relative Comparison of Conifer Conversion

The results summarized above indicate certain conditions where both hardwood management and conifer management may be financially feasible, given the assumptions about management regimes and yields, costs, prices, and discount rates. Given these findings, we can expect future growth of hardwoods under three conditions:

1) active management (natural regime) on hardwood sites. This represents conscious management of the better hardwood sites where management is demonstrated to be economically feasible and where conifer management is submarginal.

2) natural, unmanaged stands on sites which are uneconomical for either hardwood or conifer management but currently support hardwood stands. These might be called "default" stands since they do not occur as a result from a specific management decision to produce hardwood but rather are the result of natural conditions in the absence of alternative management activity.

3) natural stands on sites which may be either economical or uneconomical for future hardwood management and which currently support conifer stands, but are submarginal for continued conifer production. Assuming that uneconomic conifer production will not persist beyond harvesting of the current stand, these lands may revert to hardwood.

It is extremely difficult to generalize about the potential of these different possibilities. As we have seen, cases 1 and 2 currently include an estimated 400,000 acres (hardwood on hardwood site). Low site conifer currently occupy an estimated 2.7 million acres which potentially fall in case 3, although it is doubtful that a substantial percentage of this land would naturally revert to hardwood. We simply lack good data on lands in this category at the moment.

In addition, we still need to consider the 1.4 million acres carried as ıardwood on conifer site." How much of this acreage can we economically onvert to conifer - if any? This is really the essence of our management roblem. Two conditions hold. First, future conifer management must be conomically justified, and second, the future management must more than ompensate for the additional costs of stand conversion.

Following the Department of Natural Resources analysis a step further, e can gain some insights into the feasibility of conversion on these sites 1 - appendix B). Our first task is to recognize the impact of a one-time dditional cost for site conversion on the financial feasibility of conifer roduction. The results tabulated in table 2 simply assumed bare land. onversion of existing hardwood stands, however, requires an additional ssumed expenditure of $225 per acre. The results of such an analysis are resented in table 3 in appendix I. The findings can be easily stated: Low nd medium sites have negative conversion values at a 7-percent discount rate hen conversion costs of $225 per acre are considered. Conversion of these ites at a 5-percent discount rate is feasible if intensive conifer management is adopted. For high site lands, conversion is generally feasible for ll ownerships and management regimes at a 5-percent discount rate and only arginally feasible at 7 percent. All these findings assume increases in rices of 2 percent per year under both constant and increasing costs. valuation of site conversion under a constant price and cost situation is ot reported, although by inference we can conclude that conversion of low ites would be unprofitable at both 5 and 7 percent, and that conversion of edium sites will become marginal even at 5 percent, as would high site conversion at 7 percent.

Conclusion

We should remain cautious about overinterpretation of the case study esults summarized in the foregoing discussion. The important point is the ecognition of the patterns revealed in these results, and the apparent sensitivity of our results to the necessary assumptions which we are required o make. Our conclusions are obviously conditioned by anticipated yields nd assumed site equivalents between hardwood and conifer. This probably emains one of the weakest points in our analysis. Further, we can see that oth the levels of costs and prices assumed, as well as the potential trends in these factors over time, are highly critical to our conversion analysis. Finally, the choice of an appropriate discount rate is significant. The difference between results using a real rate of 5 percent and 7 percent illustrate the sharp impact of interest rates on economic feasibility.

Needless to say, the application of economic analysis requires that each land manager carefully assess the specifics of his forest land and the site-specific yield, costs, and value relationships. Generalized results such as those discussed here can only illustrate basic principles. Management decisions require much more detailed analysis of the actual on-the-ground conditions faced by each landowner or manager. Should we convert? It all depends!

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Appendix I

CALCULATION OF A SAMPLE PROBLEM

The following sample calculation illustrates the analysis of the choice of converting a red alder stand immediately at age 15 to conifer. The assumed rotation for red alder is 45 years (for both the present stand and future stands) and 70 years for conifer. The discount rate is 9 percent. All costs and returns are as shown in the sample calculations. The present value of retaining red alder, with the present stand held to age 45, is \$17.47. The present value of immediate conversion to Douglas-fir on a 70-year rotation is -\$26.05. All assumed costs and revenues are only illustrative (3).

<u>The Present Net Worth of Retaining Red Alder</u>

$$\begin{bmatrix}\text{Present value of} \\ \text{perpetual series} \\ \text{of red alder yields}\end{bmatrix} = (299.23)\left[\frac{(1.09)^{45}}{[(1.09)^{45}-1]\,(1.09)^{45-15}}\right]$$

$$= \$23.03$$

$$\begin{bmatrix}\text{Present value of} \\ \text{annual red alder} \\ \text{management costs}\end{bmatrix} = (0.50)\left[\frac{1}{0.09}\right]$$

$$= \$5.56$$

$$\begin{bmatrix}\text{Present net worth} \\ \text{of retaining} \\ \text{red alder}\end{bmatrix} = \$23.03 - \$5.56 = \boxed{\$17.47}$$

The Present Net Worth of Replacing Red Alder With Douglas-Fir

$$\left[\begin{array}{c}\text{Present value of}\\\text{existing red}\\\text{alder stand}\end{array}\right] = (66.01)\left[\frac{1}{(1.09)^0}\right] = \$66.01$$

$$\left[\begin{array}{c}\text{Present value of}\\\text{annual red alder}\\\text{management costs}\end{array}\right] = (0.50)\left[\frac{(1.09)^0 - 1}{0.09(1.09)^0}\right] = \$0.00$$

$$\left[\begin{array}{c}\text{Present net worth}\\\text{of existing red}\\\text{alder stand}\\\text{BEFORE CONVERSION}\end{array}\right] = \$66.01 - \$0.00 = \$66.01$$

$$\left[\begin{array}{c}\text{Present net worth}\\\text{of site preparation}\\\text{costs at CONVERSION}\end{array}\right] = (70.00)\left[\frac{1}{(1.09)^0}\right] = \$70.00$$

$$\left[\begin{array}{c}\text{Present value of}\\\text{cost of periodically}\\\text{establishing Douglas-fir}\end{array}\right] = (80.00)\left[\frac{(1.09)^{70}}{[(1.09)^{70} - 1](1.09)^0}\right] = \$80.19$$

$$\left[\begin{array}{c}\text{Present value of}\\\text{cost of periodic}\\\text{brush control}\end{array}\right] = (40.00)\left[\frac{(1.09)^{70}}{[(1.09)^{70} - 1](1.09)^{0+5}}\right] = \$26.06$$

$$\left[\begin{array}{c}\text{Present value of}\\\text{annual Douglas-fir}\\\text{management costs}\end{array}\right] = (0.60)\left[\frac{1}{0.09(1.09)^0}\right] = \$6.67$$

$$\left[\begin{array}{c}\text{Present value of}\\\text{perpetual series of}\\\text{Douglas-fir yields}\end{array}\right] = \left[\frac{(1.09)^{70}}{[(1.09)^{70} - 1](1.09)^0}\right]\left\{\left[\frac{436.50}{(1.09)^{25}}\right] + \left[\frac{769.50}{(1.09)^{40}}\right] + \left[\frac{922.50}{(1.09)^{55}}\right] + \left[\frac{3,180.00}{(1.09)^{70}}\right]\right\} = \$90.86$$

$$\left[\begin{array}{c}\text{Present net worth of}\\\text{perpetual Douglas-}\\\text{fir management}\\\text{AFTER CONVERSION}\end{array}\right] = \$90.86 - \$80.19 - \$26.06 - \$6.67 = -\$22.06$$

$$\left[\begin{array}{c}\text{Present net worth}\\\text{of converting red}\\\text{alder to Douglas-fir}\end{array}\right] = \$66.01 - \$70.00 - \$22.06 = \boxed{-\$26.05}$$

Table 3--*Conifer reclamation or hardw*

[illegible]	Rotation (Years)	Forest Industry ownership							
		Site							
		High		Medium		Low		High	
		Real interest rate (Percent)		Real interest rate (Percent)		Real interest rate (Percent)		Real interest r (Percent)	
		5	7	5	7	5	7	5	7
		- - -Two percent rate of increase in prices and costs- - -						- - - - - -	
Stand	50	113	(97)[1]	(39)	(146)	(112)	(168)	241	(63)
Establishment	60	162	(104)	40	(135)	(88)	(169)	317	(71)
Thinning	50	418	15	186	(69)	(13)	(138)	643	78
	60	388	(21)	187	(88)	12	(144)	585	21
Intensive	50	330	(36)	118	(106)	(39)	(157)	542	17
(No CT)	60	333	(70)	126	(127)	(14)	(164)	553	(31)
Intensive	50	465	27[2]	225[2]	(60)	15	(136)	684	83[2]
	60	474[2]	4	220	(81)	39[2]	(141)	686[2]	46
		Two percent rate of increase in prices with constant costs						- - - - - - - -	
Stand	50	153	(67)	(2)	(118)	(77)	(142)	289	(29)
Establishment	60	204	(74)	79	(107)	(52)	(143)	368	(36)
Thinning	50	461	47	226	(40)	25	(110)	698	116
	60	433	11	229	(58)	52	(115)	642	60
Intensive	50	388	4	173	(67)	15	(120)	623	70
(No CT)	60	393	(30)	182	(88)	40	(127)	635	23
Intensive	50	523	67[2]	280	(21)	68	(99)	765	136[2]
	60	534[2]	45	277	(42)	94[2]	(103)	768[2]	100

[1] Parentheses denote negative values.

[2] Highest positive Land Expectation Values for each price and cost combination and interest rate.

Source: Washington Department of Natural Resources. Forest Productivity Study, Phase II.

...version. Land expectation values per acre

Public ownership				Other private ownership					
Site				Site					
Medium		Low		High		Medium		Low	
...eal interest rate (Percent)		Real interest rate (Percent)		Real interest rate (Percent)		Real interest rate (Percent)		Real interest rate (Percent)	
5	7	5	7	5	7	5	7	5	7
- - - - - - - - - -Two percent rate of increase in prices and costs- - - - - - - - - - - - - - - - - - - -									
7	(143)	(107)	(183)	149	(99)[1/]	(36)	(158)	(122)	(184)
128	(125)	(70)	(183)	212	(107)	65	(144)	(91)	(184)
318	(41)	32	(142)	500	25	232	(69)	(3)	(149)
310	(72)	67	(151)	452	(24)	226	(95)	27	(156)
221	(94)	(16)	(175)	408	(30)	148	(115)	(42)	(176)
237	(122)	24	(184)	415	(72)	161	(140)	(8)	(184)
340[2/]	(44)	51	(150)	539	31[2/]	256[2/]	(69)	17	(154)
323	(79)	68[2/]	(163)	542[2/]	0	244	(98)	35[2/]	(163)
- - - - - - - -Two percent rate of increase in prices with constant costs- - - - - - - - - - - - - - - - - - -									
56	(110)	(59)	(149)	202	(63)	13	(124)	(77)	(152)
178	(91)	(20)	(148)	268	(69)	117	(109)	(44)	(152)
373	(3)	87	(104)	558	65	286	(32)	48	(113)
367	(33)	124	(112)	513	17	283	(57)	80	(120)
302	(41)	65	(122)	488	22	224	(65)	30	(128)
320	(68)	107	(130)	498	(18)	239	(89)	65	(135)
421[2/]	9[2/]	132	(97)	619	83[2/]	332[2/]	(19)	89	(106)
406	(25)	150[2/]	(109)	624[2/]	53	321	(47)	108[2/]	(115)

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TTING LANDSCAPE PERSPECTIVES OF CLEARCUT UNITS

Roger H. Twito

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service
Portland, Oregon

Contents

Abstract

The esthetics of clearcut units potentially visible from a distance can be improved by judicious design. Screening clearcuts from view or shaping them to characterize natural openings are current methods used for this purpose.

Perspective plots illustrating how proposed clearcut units will look from specific off-site viewing points provide an appropriate means of evaluating how well the units meet desired visual objectives. This procedure has been automated on a desk-top computer system using digitizer, plotting peripherals, and topographic maps. The explanations, listings, and logic are included in this report.

KEYWORDS: Landscaping, clearcutting systems, logging operations analysis/design, computers (desk-top).

Introduction

Highly visible clearcuts that reduce the beauty of forested landscapes have caused increased public censure over the past decade. Corresponding efforts to protect the scenic quality of timber-producing land have resulted in revised cutting practices. These avert clearcut units which would, from distant vantage points, appear as stark, artificial, and geometric openings. Instead units are designed to resemble natural clearings or, in those places where landscapes are of higher visual importance, the clearcuts are completely screened from view.

Applying these landscape management practices to proposed clearcut units necessitates special analytical techniques. Ideally these techniques must provide a fast and convenient means of examining the visual effects of several harvest plans in order to find the best arrangement.

This paper presents a technique that is successfully meeting this need. It requires a topographic map, desk-top computer, digitizer, and plotter. The procedure creates accurate perspective illustrations (plots) of cutting unit boundary lines and other key topographic features. Its simplicity and speed make it ideal for direct operation by the landscape designer. This permits immediate interaction between the designer and the plot, with rapid "back and forth" convergence towards the best design. In addition, this technique provides information which can facilitate the field location and marking of unit boundaries. The information should be useful to those land managers concerned with both the marketable and nonmarketable values of their resource, and more specifically to landscape architects and logging engineers teamed for the purpose of planning timber harvests that meet visual objectives.

Perspective Plot Program

BASE MAP

To produce a perspective plot of a proposed clearcut unit, a contour base map similar to figure 1, including the following information, is needed.

1. Proposed clearcut unit boundary
2. Critical viewing points
3. Key ridge lines
4. Starting points for digitizing units
5. Azimuth from viewing point to the first point on cutting unit
6. Tree heights

Essential information from the base map is resolved into numeric coordinates by the digitizer, and transmitted to the computer for analysis. The result, a perspective plot, is graphically displayed on the plotter. The numeric coordinates are retained in memory for automatic replotting of the initial unit from various other viewpoints.

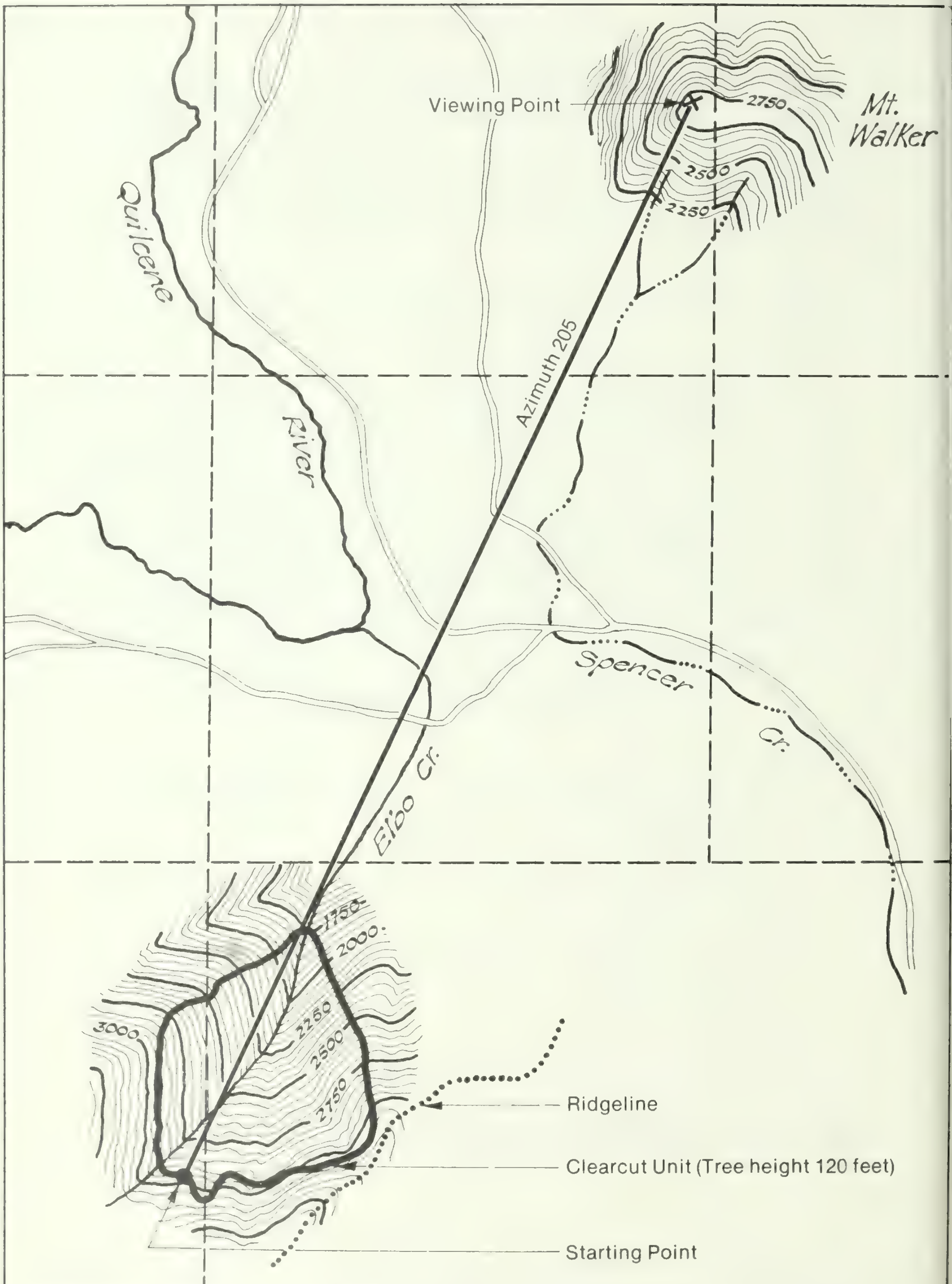


Figure 1.--Base map.

OUTPUT

The primary outputs of this program are the perspective plots. Figure 2 represents a sample of this output. It was generated from the base map data of figure 1.

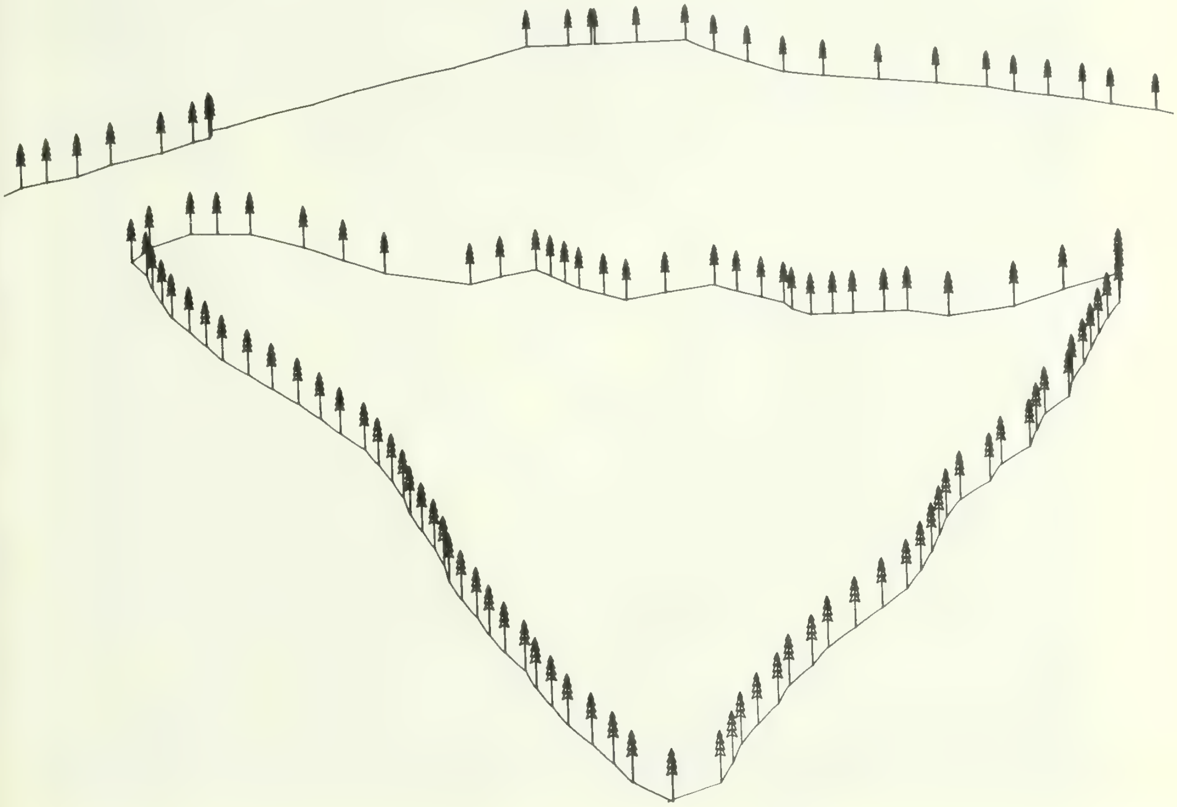


Figure 2.--Perspective plot of clearcut unit.

A special feature of PERSPECTIVE PLOT's output is that trees are only plotted at digitized points, and these points are generally digitized only at locations where contour lines cross the unit boundary. Note in figure 2 that trees appear more widely spaced along the upper part of the unit where the boundary does not intersect as many contour lines. The user of the program, however, can easily learn to relate the plot to reality. Figure 3, which merges a photograph of the same clearcut unit with figure 2, illustrates this relationship. Note that the plotter draws a line between the base of adjacent plotted trees. This line, which represents the boundary of the unit, is only a design aid.

Nevertheless, PERSPECTIVE PLOTS do provide output which, in spite of some artificiality, represent an accurate picture of clearcut units. Once the characteristics of the output are understood, the user can accurately determine a unit's shape and visibility from key viewing points.

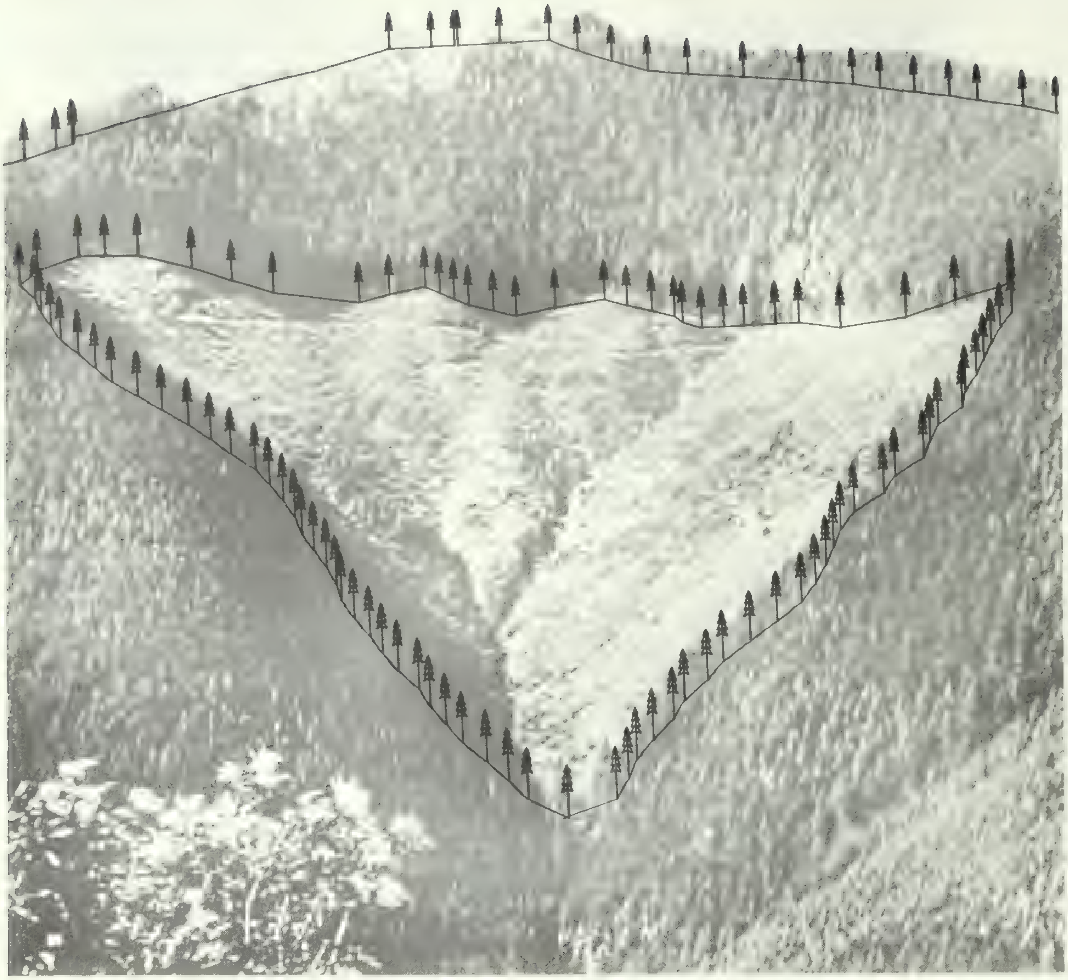


Figure 3.--Actual clearcut unit merged with perspective plot.

DESIGN PROCESS

In its simplest form, use of PERSPECTIVE PLOT in a design process is like looking in a mirror to see if one's grooming is adequate for public display. A higher degree of complexity, however, is introduced when logging costs are considered. Therefore, the following procedure is recommended.

Draw the proposed clearcut unit boundaries on a contour map. Then, with reference to selected viewing points, produce perspective plots of the unit.

Determine from these plots whether this unit will satisfy the visual requirements. While this evaluation may seem an inherently subjective process, professional scrutiny by landscape architects referencing well-defined visual criteria normally results in consistent judgments.

If these units do not satisfy the visual standards, they must be modified until a design has been produced that does display acceptable visual results.

Once an acceptable design is achieved, the logging costs associated with harvest of the unit should be estimated. If certain boundary irregularities add significantly to the unit's logging cost, the visual advantages added by these should be illustrated by comparative plots. If these advantages are not deemed worth the extra cost, alternative designs should be examined.

Though the concept and philosophy of this design process is quite simple, its implementation is not. An almost infinite number of clearcut boundary patterns, each with their associated logging costs, represent possible solutions. Professional skill, judgment, and teamwork are required for rapid convergence upon an acceptable plan. Use of PERSPECTIVE PLOT has greatly facilitated this design process by permitting the designer to quickly examine several reasonable approaches in the effort to select the best arrangement.

FIELD LOCATION OF UNIT

After the initial unit design has been completed, the problem remains of getting the clearcut boundaries of the unit marked on the ground to correspond with the map delineation. The PERSPECTIVE PLOT program provides helpful information for performing this task. Complete survey information (fig. 4) provides data needed to run a closed traverse survey connecting the digitized boundary points.

The key elements to this survey should include the following steps:

1. Identify on aerial photographs a point close to the proposed unit boundary.

2. Resolve the map location of this point, and a field survey tie to an identifiable elevation point on the unit boundary.

3. Begin the closed unit traverse at this point, and run the survey to correspond with the horizontal distances and azimuths as shown in figure 4. (Actual ground variations normally will cause discrepancies from the slope distance output as on figure 4.)

4. Record actual slope distance and percent.

5. When the survey is closed, compare actual elevation changes with the topographic map data shown on figure 4 type printout.

6. Good judgment may indicate the PERSPECTIVE PLOT routine be rerun using actual field survey data resolved into a corrected topographic base map.

If the harvest unit is to be yarded by long-span skylines (or other terrain sensitive methods) and requires field run skyline profiles to assure the feasibility and coverage limits of the yarding system, a different approach is indicated. It then is more efficient to locate the unit boundary from the measured skyline profiles.

LIMITATIONS

THE PERSPECTIVE PLOT program is based on plane analytical geometric derivations (appendix B) and does not compensate for the earth's curvature or atmospheric refraction. At the viewing range where the program is generally used, this correction is of

Figure 4.--Survey notes of clearcut unit.

[illegible]

[illegible] DEGREES

[illegible]	SLOPE DIST.	%SLOPE	HOR. DIST.	STARTING ELEV.
[illegible]	166.[illegible]	24.8	[illegible]	2920
[illegible]	[illegible]	[illegible]	121.7	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	303.7	[illegible]	[illegible]	3040
[illegible]	193.[illegible]	[illegible]	[illegible]	3000
[illegible]	103.[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
346	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2960
[illegible]	265.[illegible]	[illegible]	265.[illegible]	2960
[illegible]	[illegible]	0.0	316.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2960
[illegible]	[illegible]	-36.7	[illegible]	2960
[illegible]	[illegible]	-60.6	[illegible]	2920
[illegible]	93.[illegible]	[illegible]	[illegible]	[illegible]
40	93.[illegible]	[illegible]	[illegible]	2840
46	[illegible]	[illegible]	[illegible]	2800
[illegible]	62.[illegible]	-84.0	[illegible]	[illegible]
60	86.[illegible]	-52.0	[illegible]	2720
[illegible]	[illegible]	[illegible]	[illegible]	2680
[illegible]	[illegible]	41.6	[illegible]	2640
60	[illegible]	-52.0	77.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
46	101.[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	[illegible]	-52.[illegible]	77.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	[illegible]	[illegible]	77.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	104.1	-41.6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
54	[illegible]	[illegible]	[illegible]	[illegible]
54	[illegible]	[illegible]	[illegible]	[illegible]
46	84.[illegible]	[illegible]	66.[illegible]	2080
[illegible]	[illegible]	67.[illegible]	59.[illegible]	[illegible]
[illegible]	[illegible]	60.[illegible]	66.[illegible]	2000
[illegible]	71.[illegible]	[illegible]	59.[illegible]	[illegible]
[illegible]	62.[illegible]	-84.0	47.6	[illegible]
[illegible]	77.[illegible]	60.[illegible]	[illegible]	1880
[illegible]	[illegible]	[illegible]	67.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	100.5	[illegible]
[illegible]	44.[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	92.6	47.9	[illegible]	[illegible]
159	81.[illegible]	56.3	[illegible]	[illegible]
[illegible]	[illegible]	56.3	[illegible]	[illegible]
[illegible]	[illegible]	95.8	41.7	2000
163	[illegible]	[illegible]	41.7	2040
170	[illegible]	59.4	67.3	[illegible]
155	71.3	[illegible]	[illegible]	[illegible]
147	62.2	84.0	47.6	[illegible]
[illegible]	57.8	95.8	[illegible]	2200
[illegible]	[illegible]	95.8	[illegible]	[illegible]
136	[illegible]	[illegible]	56.0	[illegible]

Figure 4.--Survey notes of clearcut unit. (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	42.0	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	59.0	[illegible]
[illegible]	[illegible]	[illegible]	37.3	[illegible]
[illegible]	[illegible]	84.0	47.6	2520
[illegible]	[illegible]	67.8	59.0	2560
[illegible]	[illegible]	45.2	88.5	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	49.8	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	47.9	83.5	[illegible]
[illegible]	[illegible]	47.9	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	59.4	[illegible]	2880
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	25.3	[illegible]	2960
[illegible]	254.3	15.9	251.1	3000
[illegible]	[illegible]	[illegible]	158.9	[illegible]
[illegible]	[illegible]	15.4	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	176.1	[illegible]
[illegible]	[illegible]	-29.0	137.8	[illegible]
[illegible]	101.5	[illegible]	[illegible]	2960
[illegible]	[illegible]	[illegible]	165.4	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2920

minor importance. It becomes increasingly important as the viewing range increases and intervening terrain partially screens the clearcut units. For example, if a user was plotting a clearcut unit that was 10 miles away, and by plane geometry determined that he could just see a point on the unit over the top of a closer ridge 5 miles away, an error would result. The effect of the earth's curvature and atmospheric refraction would result in this point being about 29 feet below its calculated position and below the actual line of sight. This error can be quantified by the following formula:

Vertical error in feet = 0.574 y (x+y)[1];

where,

x = distance in miles from viewpoint to intervening ridge,
y = distance in miles from intervening ridge to clearcut unit.

An error of this magnitude would result in a slight discrepancy between PERSPECTIVE PLOT's graphic representation of the unit's exposure and reality. To whatever extent this occurs, PERSPECTIVE PLOT always errs on the conservative side, portraying more unit exposure than reality. Generally units plotted at the range where this factor becomes significant appear so tiny that anything beyond cursory analysis is of questionable value.

---

[1] Van Wagner, C. E. 1965. The effect of the earth's curvature in visibility mapping. USDA For. Serv., Fire Control Notes, Vol. 26, No. 4. Washington, D.C.

The PERSPECTIVE PLOT program locates and plots topographic points regardless of whether they are actually visible or not. Therefore, the screening effect of foreground terrain must be considered, as it may hide the clearcut units. Plotting the key foreground ridges makes obvious what, if any, portion of the unit will be screened. So, while the operator is spared the tedium of plotting every grid elevation point on the base map, he must use good judgment to select the topography that is essential to the plot. Past experience with this program has shown that most operators quickly relate to the plots which portray familiar landscapes and become proficient in this regard.

User's Guide

Detailed operating instructions and the program listing are given to apply to computer systems programable in the American Standard Code for Information Interchange (ASCII) BASIC language.[2/] They were developed on a Hewlett-Packard 9830A[3/] desk-top calculator/plotter/digitizer system, but can be executed on other equivalent hardware.

The minimum Hewlett-Packard calculator system needed to run this program is:

--model 9830A calculator with 7904 words of read/write memory

--additional read-only memories

plotter control

string variables

extended I/O

--plotter (9862A)

--digitizer (9864A)

--thermal page printer (9866A)

OPERATING PROCEDURE

The operating procedures outlined in this section presume a knowledge of the Hewlett-Packard Model 9830 system procedures. Only supplemental instructions pertaining to this program will be detailed.

This program can be put on a magnetic tape cassette. The first file on this tape contains special function key statements which are important to the execution of the program. Therefore, the first step in the use of this program is:

1. Type LOAD KEY 1, press EXECUTE.

   This will load instructions into the special function keys. These are labeled on the special function card (fig. 5). Explanations of the correct uses and purposes of these keys are given in table 2 (page 11).

[2/] 1977. A.N.S.I. Standard x 3.4. Amer. Nat. Stan. Lists, 20 p. New York, N.Y.

[3/] The use of trade, firm, or corporation names in this publication is not an official endorsement or approval by the U.S. Department of Agriculture of any product to the exclusion of others which may be suitable.

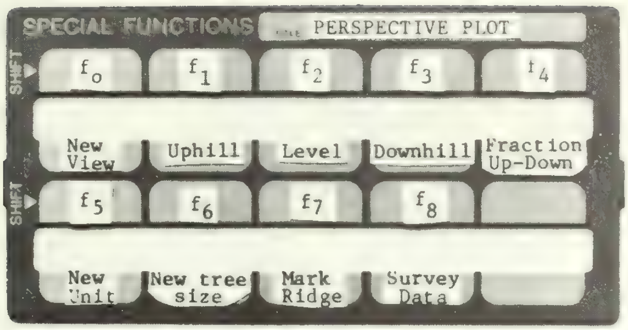


Figure 5.--Special function card for perspective plot program.

2. Press LOAD, 2, EXECUTE.

   This loads the main program.

3. Secure contour map to digitizer surface.

   Map must contain the input data similar to figure 1 including:

   --*proposed clearcut unit(s) accurately outlined*

   --*critical viewing point(s) marked*

   --*ridge lines identified (or identifiable)*

4. Place plot sheet in plotter and set margins for full 10-inch by 15-inch plot.

5. Press RUN, EXECUTE.

   At this point, the program assists the user by requesting input through visual prompters in the display.

   Continue through entries in table 1 which relate the keyboard and digitizer inputs to the visual prompters on the computer display.

Table 1--*Input explanation for perspective plot program*[1/]

Visual prompter on display	Sample keyboard response	Explanation
UNIT UPHILL OF VIEW PT? (YES/NO)	YES	The plotter draws a level line of sight mark + to reserve the bulk of the plotting space above it when the units are uphill of the viewing point, or visa versa.
ENTER DESIRED FOCAL LENGTH (IN.)	18	See figure 6 for explanation.
ENTER MAP SCALE (FEET/INCH)	1320	Refers to base map on digitizer.
ENTER CONTOUR INTERVAL (FEET)	40	Inputs contour interval from the topographic base map.
ENTER TREE HEIGHT (FEET)	140	This should be varied as the average stand height of timber surrounding the unit(s) varies to ascertain the extent of screening which will occur from the viewing point(s).
DIGITIZE VIEWING POINT	None (response via digitizer)	1. Center digitizer cursor cross hairs on the map point from which you wish to construct view of the proposed units (i.e., the viewing point). 2. After digitizer emits a short beep, press $\boxed{0}$ and then $\boxed{S}$ buttons on the cursor.
ENTER ELEVATION OF VIEWING POINT	1600	From the contour map, enter the interpolated elevation of this viewing point.
DIGITIZE 1ST POINT ON CUT UNIT	None	1. With either the template suggested in figure 6 or good judgment, pick an initial point on one cutting unit centered so desired viewing field will not fall outside of plotting capability. 2. Center cursor cross hairs near this point, preferably where a contour line intersects the proposed unit boundary. 3. Press the $\boxed{S}$ button on the digitizer cursor after hearing the beep.
ENTER ELEVATION OF 1ST POINT	3520	Enter the contour line elevation of this point.
SELECT SLOPE AND PROCEED	Press appropriate function key; e.g., f_1 UPHILL f_2 LEVEL f_3 DOWNHILL f_4 FRACTIONAL	1. The key pressed must correspond with direction of slope of the unit boundary commencing at the first point and digitizing clockwise around the unit. 2. Digitizing the unit in a counter-clockwise direction will result in erroneous output of survey information (key f_8).

[1/] Table 2 explains the role and use of special function keys.

Table 2--*Explanation of role and use of special function keys*[1/]

Key	Visual prompter on display	Sample keyboard response	Explanation
f_1	UPHILL	Digitize	1. After the digitizer beeps, press the $\boxed{S}$ button when the cursor cross hairs are centered on the contour line/unit boundary intersection immediately uphill of the last point digitized. 2. Continue moving uphill, centering the cross hairs on the contour line/unit intersections and pressing the $\boxed{S}$ button after each beep. 3. The display flashes the elevation after each point is digitized. The elevation is increased by increments equal to the contour interval with each point digitized. The elevation reading provides a check for the operator.
f_2	LEVEL	Digitize	Operate in the same manner as the f_1 key. The difference is that the elevation of all points digitized is held constant.
f_3	DOWNHILL	Digitize	Operate the same way as the f_1 key. This key, however, subtracts the contour interval from the elevation of the previously digitized point.
f_4	FRACTIONAL (+ UPHILL; - DOWNHILL)	-.5, Digitize	1. This key permits plotting of additional map points interpolated between contour lines. 2. Care must be taken to continue plotting in this mode (i.e., don't change to UPHILL or DOWNHILL mode) until the elevation equals the elevation of a plotted contour line. Example: If the contour interval is 40 feet, and the operator wants to plot 10-feet-elevation increments downhill, enter -.25 and digitize four times at interpolated quarter points between the contour lines.
	When the plotting of an individual harvest unit is complete, and it is necessary to plot additional harvest units *press: STOP, f_5*		
f_5	MARK NEW HARVEST UNIT		This message will be displayed for 2 seconds. The plotter pen will lift and the next message will be displayed.
	DIGITIZE 1ST POINT ON NEXT UNIT	Digitize	Center the cursor's cross hairs on any contour line/unit boundary intersection point on the next unit, and press the $\boxed{S}$ button after the digitizer's "beep".
	ELEVATION OF 1ST PT ON NEXT UNIT =	4000	From the contour base map, enter the elevation of the point digitized.
	SELECT A SLOPE AND PROCEED	f_1 f_2 f_3 or f_4	Press the special function key that corresponds with the contour line route which will initiate the unit boundary traverse, and proceed as previously described.

See footnote at end of table.

Table 2--*Explanation of role and use of special function keys*[1/] - continued

Key	Visual prompter on display	Sample keyboard response	Explanation
	When it is necessary to change tree height		
	press: STOP, f_6		
f_6	NEW TREE HEIGHT	90	1. Program can be interrupted at any time to make changes in the tree size. 2. The program will continue operating with the same slope (up, down, or level) as before. 3. If both a new tree size and slope change are required, first change the tree size, then press STOP again and press the special functi key for the desired new slope, and continue digitizing.
	When the plotting of all the harvest units is complete, and it is necessary to plot additional topographic features		
	press: STOP, f_7		
f_7	MARK TOPOG FEATURE OR RIDGE		This message will be displayed for 2 seconds. Then the plotter pen will lift and the next message will be displayed.
	D'TIZE 1ST PT ON TOPOG FEATURE	Digitize	Center the cursor's cross hairs on any contou line point that also describes a point on the topog feature which the operator wishes to delineate.
	ELEV. OF 1ST TOPOG POINT =	4280	Enter the elevation from the contour base map of the point digitized. 1. This operates similarly to special functi key f_5 and may appear to be an unnecessary duplication. This separation, however, was done for the purpose of labeling groups of digitized points for greater selectivity and control on the survey notes and re-plot features of the program. 2. If survey notes for the harvest units are needed, the operator must be cautioned to digitize all harvest units before digitizing any ridges. Otherwise the survey notes will not be printed for any units digitized after the first ridge is marked. 3. It may be necessary or advantageous to plot some ridges before some of the harvest units are plotted and still obtain survey note for all the harvest units. This can be done simply by labeling every new ridgeline or unit as a new harvest unit. Superfluous survey not and erroneous area calculations will be printe for the ridgelines, but the necessary survey data will also be printed for all the actual harvest units.
	To obtain a listing of the survey data required for field layout of the harvest units		
	press: STOP, f		

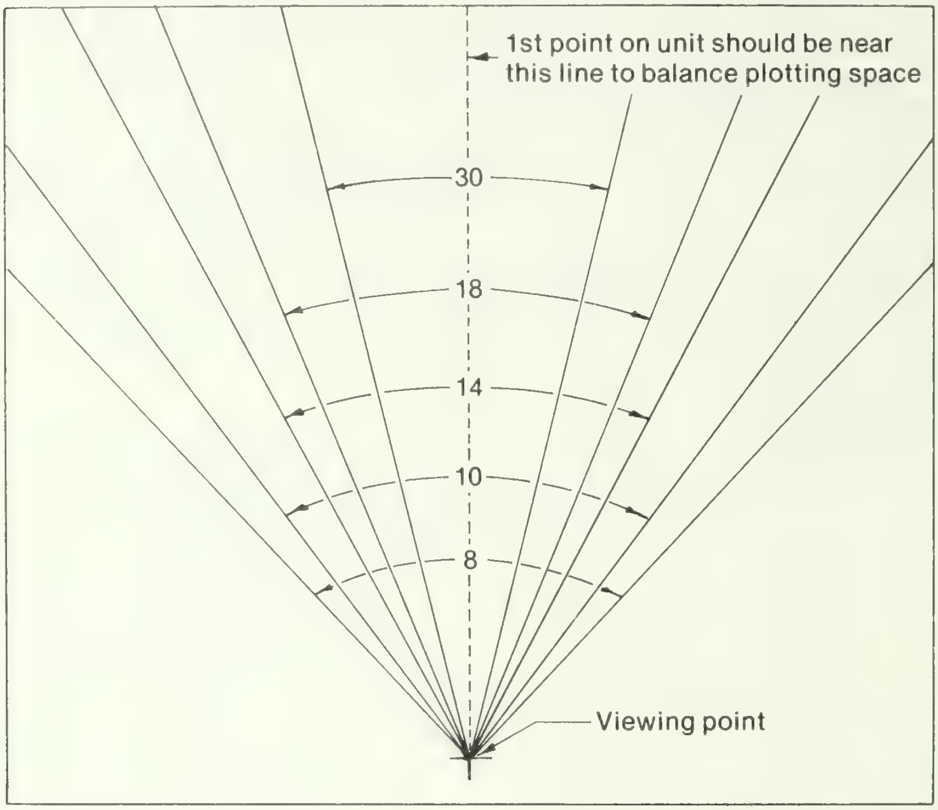
See footnote at end of table.

Table 2--*Explanation of role and use of special function keys*[1/] - continued

Visual prompter on display	Sample keyboard response	Explanation
AZIMUTH-V.P. TO 1ST POINT ON UNIT	16	1. From the contour base map, determine the magnetic bearing from the last viewing point to the first point on the unit. 2. A complete printout of survey notes for all harvest units marked will be printed (fig. 4).
When all the harvest units and key topographic features within the viewing field have been plotted and a different perspective plot of these features from a different viewing point is required, put a clean sheet of paper in the plotter and *press: STOP,* f_o		
DIGITIZE VIEWING POINT	Digitize	Center the cursor's cross hairs on the new viewing, and press the $\boxed{S}$ button after the digitizer's "beep".
ENTER ELEVATION OF VIEWING POINT	1680	Enter the elevation from the contour map of this viewing point.
DIGITIZE 1ST POINT ON CUT UNIT	Digitize	1. This gives the operator an opportunity to re-center the plot from the new viewing point. 2. Use the template from figure 6 for picking a first point that will provide for inclusion of all the points plotted from the initial viewing point. 3. The focal length, Q8 (Prog. Statement 150) can be changed if necessary.
ENTER ELEVATION OF 1ST POINT	3380	Enter the contour elevation of this point.
PLOT COMPLETE		1. This message is displayed when the previously digitized points are plotted with respect to the new viewing point. 2. This process can be performed repeatedly from additional viewing points by repetition of the outlined instructions.
REPLOT MEMORY FULL		1. If the original plot should ever accumulate 512 topographic points in memory, this message will be displayed to warn the operator that any additional plotting will prevent re-plots from memory through special function key f_0.

[1/] Special function keys can be accessed *anytime* during the program operation by pressing STOP and the appropriate special function key.

Figure 6.--Width of field for various focal lengths (numbers are focal length values).



Focal Distance Response:

1. This establishes width of viewing field attainable with the maximum 15-inch horizontal plot limit established.
2. If 18 (inches) is entered, the plot will be constructed to appear at true viewing size if the plot is held 18 inches from the viewer's eye, and correspondingly for other values entered.
3. To use the program, construct an overlay template as shown above to aid in centering the plot, and select a focal length value that will enable the entire field of digitized data to be included on one plot. Or maybe the program user will want to have the view constructed at a larger scale and use two or more plot sheets with some overlap plotted to obtain a larger scale and/or wider angle view. In any case, the template will be advantageous for correct construction of these views.
4. The half angles measured for this template are:

30-inch focal length = 14.0°
18-inch focal length = 22.6°
14-inch focal length = 28.2°
10-inch focal length = 36.9°
8-inch focal length = 43.2°

Appendix A

PROGRAM LISTINGS

```
10 REM ****PROGRAM:PERSPECTIVE PLOT
30 DIM B$[3],A[256,8]
40 M=N=0
50 DISP "UNIT UPHILL OF VIEW PT? (YES/NO)"
60 INPUT B$
70 IF B$="YES" THEN 100
80 SCALE -7.5,7.5,-7,3
90 GOTO 110
100 SCALE -7.5,7.5,-3,7
110 PLOT -0.3,0,-2
120 PLOT 0.3,0,-1
130 PLOT 0,0.3,-2
140 PLOT 0,-0.3,-1
150 DISP "ENTER DESIRED FOCAL LENGTH (IN.) ";
160 INPUT Q8
170 DISP "ENTER MAP SCALE (FEET/INCH)       ";
180 INPUT H
190 DISP "ENTER CONTOUR INTERVAL (FEET)     ";
200 INPUT C
210 DISP "ENTER TREE HEIGHT (FEET)          ";
220 INPUT K
230 DISP "DIGITIZE VIEWING POINT            ";
240 WAIT 2000
250 WRITE (9,*)
260 ENTER (9,*)X1,Y1
270 DISP "ENTER ELEVATION OF VIEWING POINT ";
280 INPUT Z1
290 IF M=1 THEN 310
300 N1=1
310 DISP "DIGITIZE 1ST POINT ON CUT UNIT    ";
320 WAIT 1000
330 WRITE (9,*)
340 ENTER (9,*)X2,Y2
350 DISP "ENTER ELEVATION OF 1ST POINT      ";
360 INPUT Z2
370 A[1,1]=X2
380 A[1,2]=Y2
390 A[1,3]=Z2
400 A[1,4]=K
410 X=X1-X2
420 Y=Y1-Y2
430 DEG
440 IF X#0 THEN 460
450 X=0.01
460 A1=ATN(Y/X)
470 Z=Z2-Z1
480 D1=SQR(X*X+Y*Y)*H
490 F=Q8*(Z/D1)
500 PLOT 0,F
```

```
510 IF [illegible]=1 THEN 2380
520 IF [illegible]=1 THEN 1640
530 DISP "SELECT A SLOPE AND PROCEED"
540 STOP
550 WRITE (2,*)
560 ENTER (9,*)X3,Y3
570 N1=N1+1
580 Z3=Z2+C1*C
590 DISP Z3
600 WAIT 250
610 IF N1>256 THEN 1070
620 A[N1,1]=X3
630 A[N1,2]=Y3
640 A[N1,3]=Z3
650 A[N1,4]=K
660 X7=A[N1,1]-X1
670 Y7=A[N1,2]-Y1
680 Z7=A[N1,3]-Z1
690 IF X7#0 THEN 710
700 X7=0.01
710 D7=SQR(X7*X7+Y7*Y7)*H
720 A7=ATN(Y7/X7)
730 A8=A1-A7
740 W=D8*TAN(A8)
750 V8=ATN(Z7/D7)
760 G=SQR(W*W+D8*D8)
770 V9=ATN((Z7+K)/D7)
780 L1=G*TAN(V8)
790 L2=G*TAN(V9)
800 R=0
810 PLOT W,L1,-2
820 PLOT W,L2
830 IF (L2-L1)<0.3 THEN 1970
840 T1=0.2*(L2-L1)
850 T2=0.5*(L2-L1)
860 IPLOT -T1*0.25,-T2*0.25,0
870 IPLOT T1*0.2,T2*0.05,0
880 IPLOT -T1*0.35,-T2*0.3,0
890 IPLOT T1*0.25,T2*0.05,0
900 IPLOT -T1*0.3,-T2*0.3,0
910 IPLOT T1*0.3,T2*0.05,0
920 IPLOT -T1*0.35,-T2*0.3,0
930 IPLOT T1*0.5,T2*0.1,0
940 IPLOT T1*0.5,-T2*0.1,0
950 IPLOT -T1*0.35,T2*0.3,0
960 IPLOT T1*0.3,-T2*0.05,0
970 IPLOT -T1*0.3,T2*0.3,0
980 IPLOT T1*0.25,-T2*0.05,0
990 IPLOT -T1*0.35,T2*0.3,0
1000 IPLOT T1*0.2,-T2*0.05,0
```

```
1010 IPLOT -T1*0.25,T2*0.25,0
1020 PLOT W,L1
1030 IF R=1 THEN 2060
1040 Z2=Z3
1050 IF M=2 THEN 2350
1060 GOTO 550
1070 M1=N1-256
1080 A[M1,5]=X3
1090 A[M1,6]=Y3
1100 A[M1,7]=Z3
1110 A[M1,8]=K
1120 IF N1=512 THEN 1170
1130 X7=A[M1,5]-X1
1140 Y7=A[M1,6]-Y1
1150 Z7=A[M1,7]-Z1
1160 GOTO 690
1170 DISP "REPLOT MEMORY FULL"
1180 STOP
1190 N1=1
1200 GOTO 690
1210 DISP "UPHILL"
1220 WAIT 1000
1230 C1=1
1240 GOTO 550
1250 DISP "LEVEL SLOPE"
1260 WAIT 1000
1270 C1=0
1280 GOTO 550
1290 DISP "DOWNHILL"
1300 WAIT 1000
1310 C1=-1
1320 GOTO 550
1330 DISP "FRACTIONAL(+UPHILL; -DOWNHILL)";
1340 INPUT C1
1350 GOTO 550
1360 DISP "NEW TREE HEIGHT";
1370 INPUT K
1380 GOTO 550
1390 DISP "MARK TOPOG FEATURE OR RIDGE"
1400 WAIT 2000
1410 N1=N1+1
1420 IF N1>256 THEN 1450
1430 A[N1,1]=A[N1,2]=A[N1,3]=A[N1,4]=-1
1440 GOTO 1470
1450 M1=N1-256
1460 A[M1,5]=A[M1,6]=A[M1,7]=A[M1,8]=-1
1470 PEN
1480 DISP "D'TIZE 1ST PT. ON TOPOG FEATURE";
1490 WAIT 2000
1500 WRITE (9,*)
```

```
1510 ENTER [illegible]
1520 DISP "ELEV. OF 1ST TOPOG POINT=";
1530 INPUT Z7
1540 N1=N1+1
1550 H=[illegible]
1560 [illegible]
1570 Q=1
1580 PEN
1590 IF Q=0 THEN 1620
1600 N1=N1-1
1610 GOTO 1630
1620 N2=N1
1630 GOTO 230
1640 FOR N1=2 TO N2
1650 IF N1>256 THEN 1710
1660 X7=A[N1,1]-X1
1670 Y7=A[N1,2]-Y1
1680 Z7=A[N1,3]-Z1
1690 K=A[N1,4]
1700 GOTO 1790
1710 M1=N1-256
1720 X7=A[M1,5]-X1
1730 Y7=A[M1,6]-Y1
1740 Z7=A[M1,7]-Z1
1750 K=A[M1,8]
1760 IF A[M1,7]=0 THEN 2110
1770 IF A[M1,7]=-1 THEN 2110
1780 GOTO 1810
1790 IF A[N1,3]=0 THEN 2110
1800 IF A[N1,3]=-1 THEN 2110
1810 IF X7#0 THEN 1830
1820 X7=0.01
1830 D7=SQR(X7*X7+Y7*Y7)+H
1840 A7=ATN(Y7/X7)
1850 A8=A1-A7
1860 W=Q8*TAN(A8)
1870 V8=ATN(Z7/D7)
1880 G=SQR(W*W+Q8*Q8)
1890 V9=ATN((Z7+K)/D7)
1900 L1=G*TAN(V8)
1910 L2=G*TAN(V9)
1920 IF N1=2 THEN 2130
1930 PLOT W,L1,-2
1940 PLOT W,L2
1950 [illegible]
1960 IF (L2-L1) <= 0.3 THEN 840
1970 T1=0.2*(L2-L1)
1980 T2=0.5*(L2-L1)
1990 IPLOT -T1/4,-T1/4,0
2000 IPLOT -T1/4,-(T2-(T1/4)),0
```

```
2010 PLOT T1,0,0
2020 PLOT -T1/4,(T2-(T1/4)),0
2030 PLOT -T1/4,T1/4,0
2040 PLOT W,L1
2050 IF R=0 THEN 1040
2060 NEXT N1
2070 PEN
2080 U=1
2090 DISP "PLOT COMPLETE"
2100 STOP
2110 PEN
2120 GOTO 2060
2130 PEN
2140 GOTO 1930
2150 DISP "PLOT COMPLETE"
2160 STOP
2170 DISP "MARK NEW HARVEST UNIT"
2180 WAIT 2000
2190 N1=N1+1
2200 IF N1>256 THEN 2230
2210 A[N1,1]=A[N1,2]=A[N1,3]=A[N1,4]=0
2220 GOTO 2250
2230 M1=N1-256
2240 A[M1,5]=A[M1,6]=A[M1,7]=A[M1,8]=0
2250 PEN
2260 DISP "DIGITIZE 1ST POINT ON NEXT UNIT ";
2270 WAIT 2000
2280 WRITE (9,*)
2290 ENTER (9,*)X3,Y3
2300 DISP "ELEV. OF 1ST PT ON NEXT UNIT = ";
2310 INPUT Z3
2320 N1=N1+1
2330 M=2
2340 GOTO 610
2350 M=0
2360 DISP "SELECT SLOPE AND PROCEED"
2370 STOP
2380 N1=N1+1
2390 A[N1,1]=A[1,1]
2400 A[N1,2]=A[1,2]
2410 A[N1,3]=A[1,3]
2420 A[N1,4]=A[1,4]
2430 GOTO 520
2440 PRINT TAB25"SURVEY INFORMATION"
2450 PRINT
2460 DISP "AZIMUTH-V.P. TO 1ST PT ON UNIT";
2470 INPUT B1
2480 WRITE (15,2490)B1
2490 FORMAT "AZIMUTH FROM VIEW POINT ... [illegible]
          [illegible] DEGREES",/
2500 PRINT "    AZIMUTH     SLOPE DIST.     [illegible]
          HOR. DIST.     STARTING ELEV. "
```

```
2510 PRINT
2520 N2=N1
2530 J1=B=0
2540 FOR N1=(1+B) TO N2-1
2550 IF N1=256 THEN 3060
2560 IF N1>256 THEN 3130
2570 P=A[N1,1]-A[N1+1,1]
2580 P1=A[N1,2]-A[N1+1,2]
2590 P3=A[N1,3]-A[N1+1,3]
2600 J=(A[N1,2]*A[N1+1,1])-(A[N1,1]*A[N1+1,2])
2610 IF A[N1+1,3]=0 THEN 2900
2620 IF A[N1+1,3]=-1 THEN 2900
2630 E1=A[N1,3]
2640 L=SQR(P↑2+P1↑2)*H
2650 P4=(P3/L)*-100
2660 P5=SQR(L↑2+P3↑2)
2670 IF P#0 THEN 2690
2680 P=0.01
2690 P6=ATN(P1/P)
2700 IF P<0 THEN 2730
2710 P7=270-P6
2720 GOTO 2740
2730 P7=90-P6
2740 IF X>0 THEN 2770
2750 B2=B1-(90-A1)
2760 GOTO 2780
2770 B2=B1-(270-A1)
2780 P8=P7+B2
2790 IF P8<0 THEN 2830
2800 IF P8>360 THEN 2850
2810 P9=P8
2820 GOTO 2860
2830 P9=P8+360
2840 GOTO 2860
2850 P9=P8-360
2860 J1=J+J1
2870 WRITE (15,2880)P9,P5,P4,L,E1
2880 FORMAT F6.0,F15.1,F12.1,F11.1,F15.0
2890 NEXT N1
2900 J2=J1*H↑2/87120
2910 PRINT
2920 WRITE (15,2930)J2
2930 FORMAT "       SIZE OF UNIT=",F8.1," ACRES",.
2940 J1=0
2950 B=N1
2960 IF N1=N2 THEN 3020
2970 IF N1 >= 256 THEN 3000
2980 IF A[N1+1,3]=-1 THEN 3020
2990 GOTO 2540
3000 IF A[N1-255,3]=-1 THEN 3020
```

```
3010 GOTO 2540
3020 PRINT "******SURVEY INFORMATION COMPLETE******"
3030 PRINT
3040 PRINT
3050 STOP
3060 P=A[N1,1]-A[N1-255,5]
3070 P1=A[N1,2]-A[N1-255,6]
3080 P3=A[N1,3]-A[N1-255,7]
3090 J=(A[N1,2]*A[N1-255,5])-(A[N1,1]*A[N1-255,6])
3100 IF A[N1-255,5]=0 AND A[N1-255,6]=0 THEN 2900
3110 IF A[N1-255,7]=-1 THEN 2900
3120 GOTO 2630
3130 M1=N1-256
3140 P=A[M1,5]-A[M1+1,5]
3150 P1=A[M1,6]-A[M1+1,6]
3160 P3=A[M1,7]-A[M1+1,7]
3170 J=(A[M1,6]*A[M1+1,5])-(A[M1,5]*A[M1+1,6])
3180 IF A[M1+1,5]=0 AND A[M1+1,6]=0 THEN 2900
3190 IF A[M1+1,7]=-1 THEN 2900
3200 E1=A[M1,7]
3210 GOTO 2640
3220 STOP
```

Appendix B

PROGRAM ALGORITHM

The key steps in the program are outlined to provide understanding of the mathematical algorithm. This is included to help those that may want to apply this technique using small computers that are not programable in ASCII BASIC.

This algorithm can be briefly described as relating solved horizontal and vertical angles from contour map input data to a plotted diagram where the viewing point is a fixed distance from the diagram. This distance, though variable, is set at 18 inches for this example.

1. Tape base map to digitizer.
2. Program the plotter to mark a point near the center of the sheet for the horizontal line of sight (a + mark is used for this in the present program). With a limited plot size, the mark should be nearer to the bottom of the plot if the plotted terrain is at a higher elevation than the viewing point, and visa versa.
3. Enter and store: H (map scale in feet/inch).
4. Enter and store: K (tree height in feet).
5. Enter and store: Digitized coordinates of the viewing point X1 and Y1 (see fig. 7).
6. Enter and store: Elevation in feet of the viewing point Z1.
7. Mark an intial point where a contour line crosses the unit boundary.
8. Enter and store: Digitized coordinates of the initial point X2 and Y2 (see fig. 7).
9. Enter and store: Elevation of initial point Z2.

(COMPUTER NOW CALCULATES PLOT COORDINATES FOR THIS INITIAL POINT BY THE FOLLOWING PROCESS.)

I. *Calculate horizontal distance from viewpoint to initial point.*

   a. $X = X2 - X1,$

   b. $Y = Y2 - Y1,$

   c. $D1 = (X^2 + Y^2)^{1/2} H,$

   D1 = true distance in feet from viewpoint to initial point.

II. *Calculate azimuth angle from viewpoint to initial point.*

   a. $A1 = \text{arc tan } Y/X.$

III. a. $Z = Z2 - Z1,$

   b. $F = 18\ Z/D1,$

   F = vertical plot in inches from horizontal reference to the ground line at the initial point, and

   $F1 = 18\ (Z + K)/D1,$

   F1 = vertical plot in inches from horizontal reference to tree top at initial point.

   The F and F1 values can be derived from proportional triangles, i.e.,

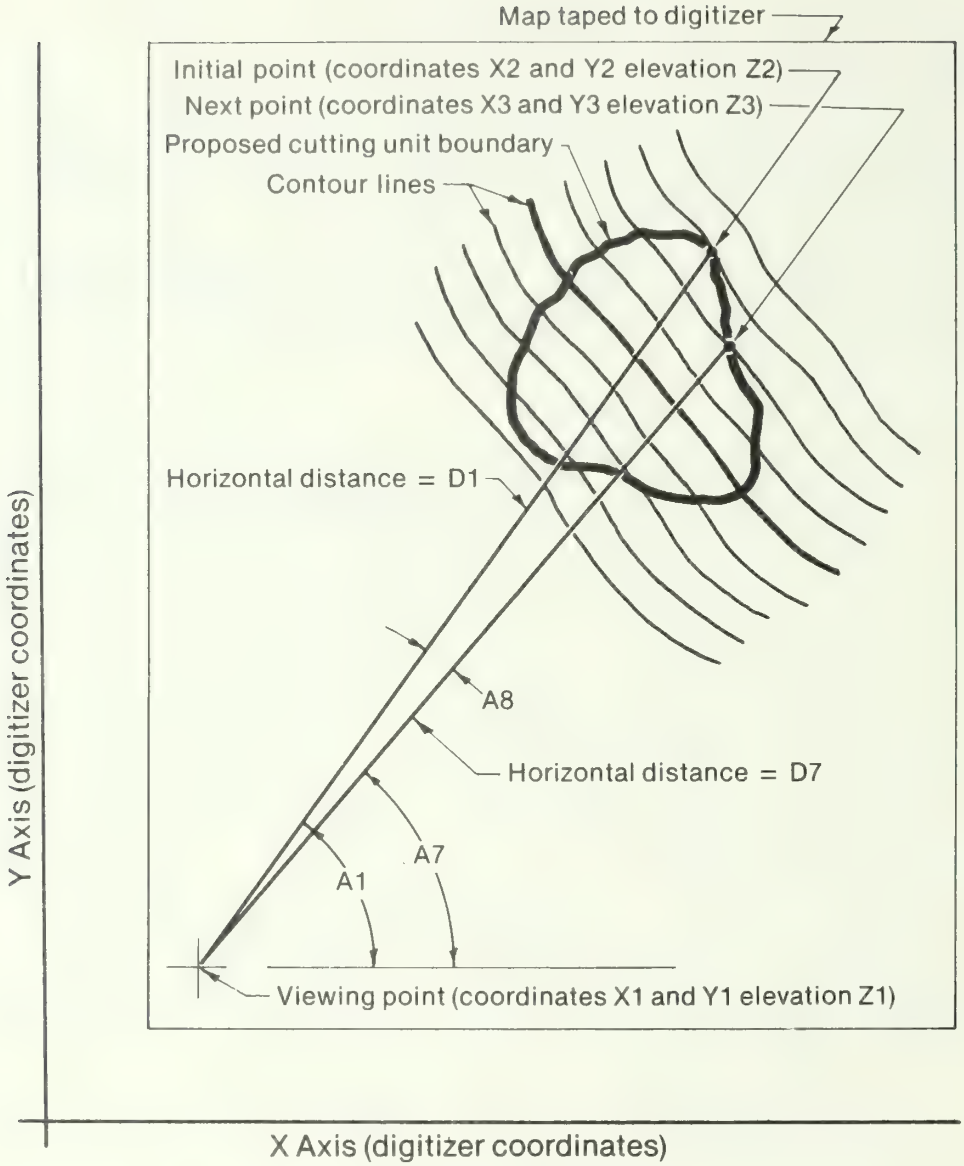
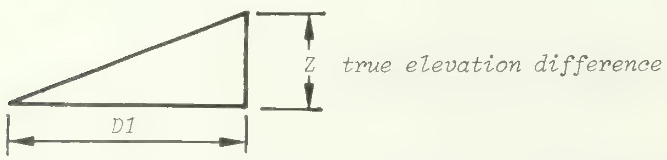
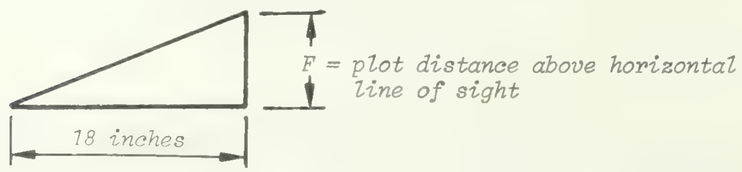


Figure 7.--Base map geometry.



true horizontal distance (viewpoint) to initial point)

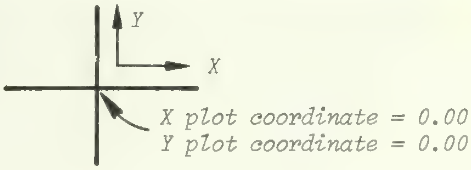
and



viewer distance from plot diagram and likewise for F1 value.

IV. To plot these calculated values for the initial point:

a. Origin must be set at horizontal line of site mark.



b. The following plot commands are needed:

(LIFT PEN)

PLOT 0 (x coord.), F (y coord.),

(which plots to base of tree at initial point),

PLOT 0, F1,

(plots to top of tree at initial point),

PLOT 0, F,

(returns plotter to base of tree).

---

10. Input additional data needed to generate plot for the point adjacent to the initial point (see fig. 7).

11. Enter and store: Digitized coordinates of the next point X3 and Y3.

12. Enter and store: Elevation of next point Z3.

(COMPUTER NOW CALCULATES PLOT COORDINATES FOR THE NEXT POINT BY THE FOLLOWING PROCESS.)

I. Calculate distance from viewing point to second point:

a. $X7 = X3 - X1$,

b. $Y7 = Y3 - Y1$,

c. $D7 = (X7^2 + Y7^2)^{1/2}H$,

$D7$ = *true distance in feet from viewing point to second point.*

II. Calculate azimuth angle from viewpoint to second point:

a. $A7 = \arctan Y7/X7$.

III. Calculate azimuth angle difference between initial point and second point:

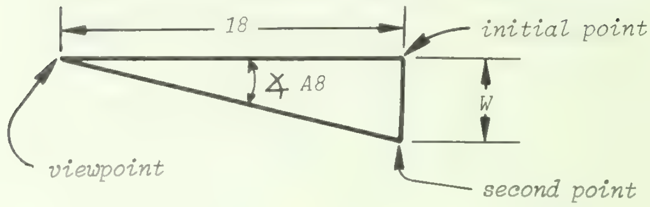
a. $A8 = A1 - A7$.

IV. Calculate "x" value to be plotted:

a. $W = 18 \tan A8$,

W = *"x" value to be plotted.*

(based on triangular relationship)



V. *Calculate "y" values to be plotted:*

a. *V8 = arc tan Z7/D7,*

and

V9 = arc tan (Z7 + K)/D7.

b. $G = (W^2 + 18^2)^{1/2}$,

G = horizontal distance from eye to "x" projection of second plotted point.

c. *L1 = G tan V8,*

L1 = "y" coordinate to plot for base of tree, and

L2 = G tan V9,

L2 = "y" coordinate to plot for top of tree.

VI. *To plot the values now calculated for the second point, the following plot commands are needed:*

(Pen down to draw line from initial point to second point),

PLOT W (x coord.), L1 (y coord.)

(which plots to base of tree at second point),

PLOT W, L2

(plots to top of tree at second point),

PLOT W, L1

(returns plotter to base of tree).

---

13. Repeat steps 10 through 12 for each additional point required.

If several clearcut units and ridgetops are plotted from one viewing point, it is desirable to lift the plotter's pen through program control or manually as it plots from one unit to the next.

Most desk-top systems can be programed to automatically calculate the elevation at each plotted point except for the initial one. This time saving modification requires entering and storing the contour line interval in feet and arranging a technique to signal the program for plotting downhill (decrementing elevation), uphill (incrementing elevation), or level (holding elevation constant).

GPO 986-501

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General Technical Report PNW-72 1978

Don Minore

THE DEAD INDIAN PLATEAU:

A Historical Summary of Forestry Observations and Research in a Severe Southwestern Oregon Environment

Pacific Northwest
Forest and Range Experiment Station
U.S. Department of Agriculture
Forest Service
Portland, Oregon

Abstract

The Dead Indian Plateau is a gently sloping area of 100,000 acres (40,000 ha) east of Ashland, Oregon. It is a valuable source of timber, but timber stands on the plateau often are difficult to regenerate after logging. Many people have been observing and studying these regeneration problems and other aspects of the Dead Indian Plateau for many years. This report is a summary of their observations, measurements, and conclusions.

Resembling a gigantic elevated saucer lying south-southwest of Mount McLoughlin, the Dead Indian Plateau has cold, snowy winters that alternate with hot, dry summers. Nocturnal freezes combine with gentle, often concave topography to produce serious frost damage in many places.

White fir constitutes the dominant tree species on much of the area, but a mixture of conifer species comprises most stands. Plateau forests are uneven aged; shrub density is low, but grasses and forbs are abundant and usually dense. These forests support large populations of rodents and deer.

Economic selection cutting on the plateau was succeeded by clearcutting shortly after World War II. Most attempts to regenerate these clearcuts were not successful, however, and various partial-cutting techniques have since been used--with varying degrees of success. A two-stage shelterwood system with underplanting seems necessary in most of the stands if the original composition is to be maintained.

Early research involved the pine beetle. Later, mistletoe and heart rot were also studied. Recent plantation trials involved overstory treatments, artificial shading, scarification, herbicides, species and stock trials, frost measurements, irrigation, and rodent caging. Indirect treatment with herbicide removal of the vegetation appears to be the best method for controlling gophers.

Work in progress includes amelioration of soil compaction, genetic studies, species trials, and continued research on gophers. Partial solutions are available for the three problems that seem to be most important in inhibiting regeneration: pocket gophers, frost, and the moisture stress produced by vegetative competition. None of these problems have been completely solved. Continued research and careful observation are appropriate and essential for progress in management on the Dead Indian Plateau.

KEYWORDS: Oregon (Dead Indian Plateau), history, regeneration (stand), management (forest).

Contents

Introduction

Approximately 10 miles (16 km) east of Bear Creek Valley and the city of Ashland, Oregon, the steep western extremities of the Cascade Range level out to form an extensive, gently sloping plateau. About 1854 some Rogue Valley settlers went to this area and found two or three deserted wigwams, in which were the bodies of two Indians--probably killed in a conflict between rival tribes (Brown 1960a). Since then, this area has been known as Dead Indian Plateau.

The plateau has been a valuable source of timber and rangeland for many years. Since World War II, however, its timber, grazing, wildlife, and recreational resources have been used at increasing rates by an expanding population. Gentle topography, an excellent road system, and nearby forest product markets should provide excellent opportunities for intensive forest management on the plateau. Unfortunately, intensive forest management is difficult on much of the area. Natural forest regeneration is often erratic, slow, or nonexistent. Growth is sometimes poor, and much of the timber is defective.

Many people have been observing, measuring, and studying the plateau and its problems for many years. Some of this work has been published, but much of it is scattered and difficult to obtain. Foresters working in the Dead Indian area should have easy access to knowledge gathered in the past as they manage the present forest resources. Researchers also should be aware of the past--repeating old experiments or seeking answers to questions that have already been answered is a waste of time, effort, and money. This report is a summary of past attempts to solve forestry problems on the Dead Indian Plateau.

LOCATION AND TOPOGRAPHY

The Dead Indian Plateau is bounded on the west by steep slopes descending to Bear Creek Valley and on the north by the precipitous slopes above Little Butte Creek and by Cox Butte, Burton Butte, and Buck Lake. Its southern boundary is generally considered to be the Green Springs Highway. No sharply defined eastern boundary exists, but it will be designated here as a line drawn from the south end of Buck Lake to Fredenburg Spring and Lincoln (fig. 1).

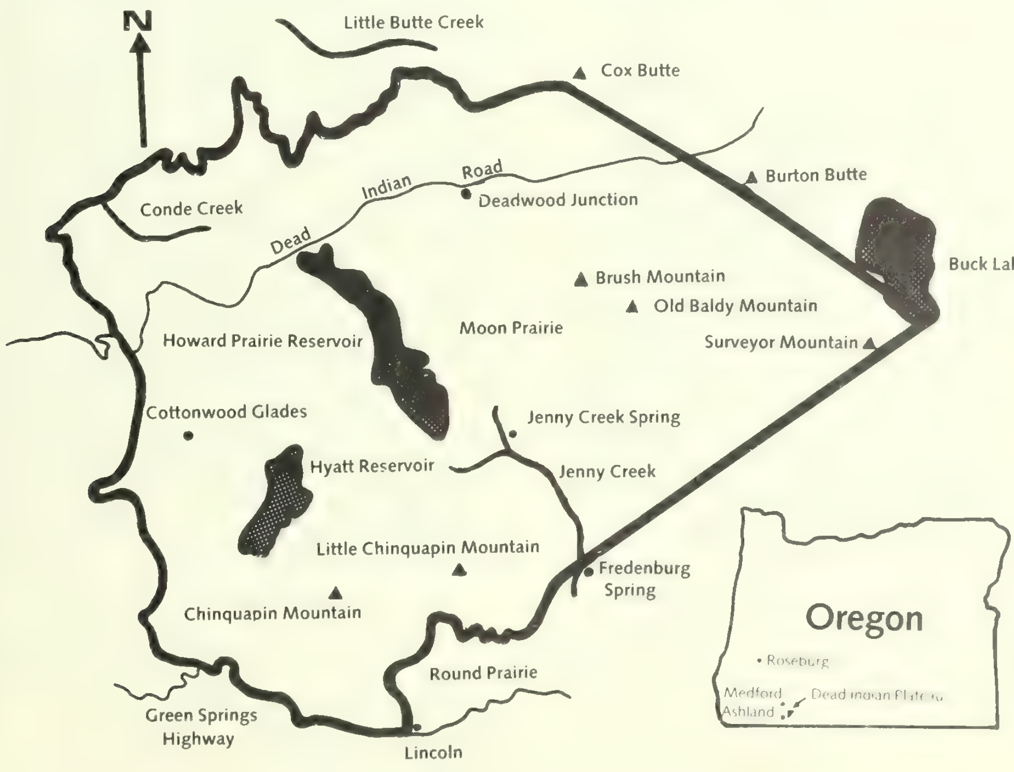

Figure 1.--The Dead Indian Plateau.

The plateau occupies approximately 100,000 acres (40,000 ha). It includes townships 38 and 39 south, ranges 3 and 4 east, Willamette Meridian. Approximately half of T. 38 S., R. 5 E., and a small portion of T. 38 S., R. 2 E., are also included.

The western edge of the Dead Indian Plateau is approximately 5,200 feet (1 600 m) above sea level. This high western edge slopes downward on both sides--precipitously to the west and gently to the east. At Howard Prairie Reservoir, near the middle of the plateau, the elevation is only 4,500 feet (1 400 m). From Howard Prairie elevation gradually increases again to the east, and the elevation of Buck Lake is 4,900 feet (1 500 m). Like a gigantic elevated saucer lying south-southwest of Mount McLoughlin, the Dead Indian Plateau tends to be lower in the center than it is on the edges. This saucer, however, is not at all uniform. Large, rather gently sloping mountains rise above the general level in many places, and the southeastern portion is drained by a great crack--the steep-sided Jenny Creek drainage. Elevations range from 3,700 feet (1 100 m) at Lincoln to 6,300 feet (1 900 m) on the top of Old Baldy Mountain.

GEOLOGY AND SOILS

The high western portion of the Dead Indian Plateau is composed of Eocene and Miocene formations of the western Cascades. They are characterized by black andesitic lavas that include laboradorite, andesine, oligoclase, rhyolite, and basalt. Thin flows of these black lavas are interbedded with gray andesitic lavas, tuffs, breccias, and agglomerates. Younger, High Cascade formations of olivine basalt comprise the plateau surface east of the high western portion (Callaghan and Buddington 1938). Chinquapin and Little Chinquapin Mountains are pre-Mazama volcanoes (Williams 1942).

Soils of the Dead Indian Plateau were all developed from andesites and basalts. Along the western edge where these volcanic parent material are of Eocene and Miocene age, clay content of the soil tends to be higher than farther east--the 840 and 850 soil series have dense clay subsoils (deMoulin et al. 1975). Even in the east, however, most of the plateau supports soils with clay loam and loam subsoils. These are the 809, 810, 880, and 882 series of deMoulin et al. They were mapped as Pokegama, Woodcock, and Oatman series by Cahoon and Simonson (1969). Depth, color, and stone content vary considerably among these younger soils, but most are well drained and stony. Although serious erosion is not a problem on most of the plateau, soil compaction occurs in some areas.

CLIMATE

Climatic conditions on the plateau are severe. Cold, snowy winters alternate with hot, dry summers. Although the mean annual temperature at Howard Prairie Reservoir is a moderate 43.7°F (6.5°C), temperature fluctuations are extreme (meteorology Committee, Pacific Northwest River Basins Commission 1969). Temperatures at Howard Prairie varied from -20°F (-29°C) to 95°F (35°C) during the 1960-65 period. The mean annual precipitation of 34.4 inches (87.4 cm) is somewhat misleading. Total winter snowfall between 1960 and 1965 ranged from 142.5 to 218 inches (362 to 554 cm). In contrast, total precipitation in July was a meager 0.1 to 0.4 inch (0.25 to 1.0 cm). Although occasional summer thunderstorms occur, July is the driest and warmest month on the Dead Indian Plateau. December is the wettest month and January the coldest (Meteorology Committee, Pacific Northwest River Basins Commission 1969). Nighttime temperatures often drop below freezing, even during the summer months. These nocturnal freezes combine with gentle, often concave topography to produce serious frost damage in many areas (fig. 2).

Figure 2.--Frost damaged white fir next to 50-inch (127-cm) diameter stump at Moon Prairie. Note flat fir top and adjacent meter stick.

VEGETATION

Vegetation on the Dead Indian Plateau generally resembles that of the mixed conifer zone described by Franklin and Dyrness (1973). White fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.)[1/] is the dominant tree species in most plateau stands, and it forms nearly pure forests above 5,500 ft (1 700 m) in the west. Elsewhere, Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) is nearly always well represented. Smaller quantities of incense-cedar (*Libocedrus decurrens* Torr.) and sugar pine (*Pinus lambertiana* Dougl.) often occur in the white fir-Douglas-fir mixtures. Ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.) is sparsely scattered over much of the plateau, but is more evident toward the east. Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.) occurs at high elevations; like ponderosa pine, it is most abundant on eastern portions of the plateau where it forms nearly pure stands above 5,500 ft (1 700 m). Western white pine (*Pinus monticola* Dougl. ex D. Don) is sometimes found with Shasta red fir, but it is never abundant. Although not present in the western and southern portions of the plateau except in local frost pickets, lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is abundant in the northeastern portion. Pacific yew (*Taxus brevifolia* Nutt.) is occasionally present in the understory; and bigleaf maple (*Acer macrophyllum* Pursh), dogwood (*Cornus nuttallii* Aud. ex T. & G.), golden chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.), Oregon white oak (*Quercus garryana* Dougl.), California black oak (*Quercus kelloggii* Newb.), and willows (*Salix* spp. L.) occur as occasional, minor components of the overstory. Although abundant at similar elevations elsewhere in southern Oregon, madrone (*Arbutus menziesii* Pursh) is absent on most of the Dead Indian Plateau and rare in the isolated areas where it does occur.

Many shrub species occur on the plateau, but shrub density is

[1/] The source for scientific names of plants is Garrison et al. (1976).

notably low throughout most of the area. Wild rose (*Rosa gymnocarpa* Nutt.) and snowberry (*Symphoricarpos albus* (L.) Blake) are almost ubiquitous, but seldom abundant. Serviceberry (*Amelanchier alnifolia* Nutt.), creambush oceanspray (*Holodiscus discolor* (Pursh) Maxim.), gooseberries (*Ribes* spp. L.), Oregon boxwood (*Pachistima myrsinites* (Pursh) Raf.), thimbleberry (*Rubus parviflorus* Nutt.), and the Oregon grapes (*Berberis nervosa* Pursh and *B. aquifolium* Pursh) also are widespread but not abundant in most places. Blue elderberry (*Sambucus glauca* Nutt. ex T. & G.), pinemat manzanita (*Arctostaphylos nevadensis* Gray), and snowbrush ceanothus (*Ceanothus velutinus* Doug. ex Hook.) are locally abundant but not widespread. Shrubs of minor importance include greenleaf manzanita (*Arctostaphylos patula* Greene), California hazel (*Corylus cornuta* Marsh.), and squawcarpet (*Ceanothus prostratus* Benth.). Poison oak (*Rhus diversiloba* T. & G.) and whipple vine (*Whipplea modesta* Torr.) are absent.

In contrast to the shrubs, grasses and forbs are abundant and usually dense on the Dead Indian Plateau. Many species are present, but the herbaceous flora is somewhat less complex and varied than that of most southwestern Oregon areas. Grasses include the fescues (*Festuca* spp. L.), bromes (*Bromus* spp. L.), and wildryes (*Elymus* spp. L.) that are common in many clearcut areas on the Dead Indian Plateau. Beneath overstory canopies the most common herbaceous species are strawberries (*Fragaria* spp. L.), snowqueen (*Synthyris reniformis* (Dougl.) Benth.), starflower (*Trientalis latifolia* Hook.), Scouler bellflower (*Campanula scouleri* Hook. ex A. DC.), threeleaf anemone (*Anemone deltoidea* Hook.), starry solomonplume *Smilacina stellata* (L.) Desf.), and sedges (*Carex* spp. L.). Beargrass (*Xerophyllum tenax* (Pursh) Nutt.) is absent.

History

WILDLIFE

The abundant grasses and forbs on the plateau support large populations of rodents and deer. Rodents, including pocket gophers (*Thomomys* spp.), are particularly numerous on clearcut areas. Large rodent populations, however, apparently were present before clearcutting was begun. A 1917 grazing report indicated that "prairie dogs and gophers were "doing considerable damage" in the Dead Indian area (Brown 1960a). Gophers probably have always been present on the plateau, but intensive trapping of fishers early in this century may have stimulated the growth of gopher populations by eliminating an important predator.[2/] Martens also probably preyed on gophers before trapping eliminated them from the Dead Indian area.

GRAZING

Grazing began many years ago on the plateau. Early access by road from the Bear Creek Valley may have contributed to this activity. Part of the area was accessible by road as early as 1850, and in 1870 the road was extended all the way to Pelican Bay on Upper Klamath Lake (Brown 1960a). Heavy grazing by sheep occurred on much of the Dead Indian Plateau from 1890 until 1940. Some grazing by cattle occurred during this period; cattle grazing increased after 1940 as the sheep were phased out.[3/] In 1913 Dead Indian was the most extensively grazed district on the Crater National Forest, and by 1917 the Cottonwood Glades and Conde Creek areas were reported to be overgrazed (Brown 1960a).

FIRE

Periodic fires probably increased the rangeland available for grazing by opening up the conifer overstory on some portions of the Dead Indian Plateau early in this century. A particularly severe fire occurred

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[2/] Mark E. Lawrence (Medford District, BLM--retired), personal correspondence, 1978.

[3/] Larsen, Lawrence P. 1975-1977. Field notes on file at the Medford District Office, Bureau of Land Management, Medford, Oreg.

in the drought year of 1910 when 2,300 acres (944 ha) burned in the Deadwood-Moon Prairie area (Brown 1960a). Part of this area burned again in 1917 (Hermann and Thomas 1963), and some of it still does not support trees (fig. 3). Fortunately, most of the plateau was not affected by these fires, and most burned areas either were not completely denuded or have since regenerated. Good cone crops for most species in 1928 probably contributed to forest regeneration in these old burns. Most species also had good seed crops in 1949, 1968, and 1971.[4/]

[4/] Larsen, Lawrence P. 1976. Klamath resource area silvicultural report. Preliminary draft on file at the Medford District Office, Bureau of Land Management, Medford, Oreg. 130 p.

LOGGING

The first timber harvesting operations on Dead Indian Plateau probably were begun early in this century with economic selection of the best old-growth trees (see footnote 4). These virgin old-growth stands contained 40,000 to 125,000 board feet to the acre, International 1/4-inch scale (360 to 1 130 m^3 per ha).[5/] A 1916 report on a fire situation stated that the timber was of inferior quality, however, and that the white fir was particularly defective (Brown 1960a). Large-scale logging operations apparently were

[5/] Lawrence P. Larsen (Medford District, BLM), personal communication, 1978.

Figure 3.--The Moon Prairie burn in 1977. This area has been poorly stocked with forest regeneration since a 1910 fire and subsequent salvage operations removed the overstory.

not started until the beginning of World War II when selective harvesting using diameter limits was employed. Douglas-firs 24 inches (61 cm) or larger in d.b.h. and white firs 18 inches (46 cm) or larger in d.b.h. were cut (see footnote 4). Timber harvesting on Bureau of Land Management (BLM) land was begun in the early 1940's. National Forest timber sales on the plateau were made in 1943 (Brown 1960b).

Date of the first tree planting on the Dead Indian Plateau has not been determined, but available records indicate that it occurred after 1943. Thirteen acres near Dead Indian Road were planted with ponderosa pine in 1949 (Brown 1960b).

Logging gradually became less selective during the 1950's, and some cutover areas began to resemble "clearcuts thinly disguised by a veneer of poles" (see footnote 4). Small group selection cuts were tried at this time, and a few small clearcuts were logged in high-elevati Shasta red fir stands (Gratkowski 195 Widespread clearcutting, however, was not started on most of the plateau until 1958 (see footnote 4). In 1958 both 20-acre clearcuts and seed tree cutting were attempted. Almost all the seed trees blew down by 1965 (see footnote 4). Clearcutting in small units was continued until 1963, but it proved to be as unsuccessful as the seed tree method (fig. 4). An intensive BLM reforestation program was started in 1958.[6] Nevertheless, less than half the BLM clearcuts in ranges 3, 4, and 5 east of township 38 south were satisfactorily stocked 12 years after cutting (see footnote 4). Most of these clearcuts were planted approximately three times after an initial 2- to 3-year delay to allow for natural regeneration that never occurred (Lawrence P. Larsen, personal communication, 1978).

[6] Lawrence, Mark E. 1963. Results and conclusions after 5 years of intensive reforestation in the Greensprings and Dead Indian areas. Memorandum on file at the Medford District Office, Bureau of Land Management, Medford, Oreg.

Figure 4.--A poorly stocked 15-year-old clearcut unit on the Dead Indian Plateau. Note the gentle topography and almost complete absence of conifer regeneration.

Regeneration difficulties probably caused both the Bureau of Land Management and the Forest Service to stop clearcutting on the Dead Indian Plateau in 1963. The Forest Service made only sanitation cuts between 1963 and 1970,[7] but BLM foresters continued to practice partial cutting after clearcutting was discontinued. They eventually introduced a three-stage shelterwood system that was applied until 1976, when a two-stage shelterwood system with underplanting was adopted. The Forest Service began shelterwood cutting on their Dead Indian lands in 1970 and began underplanting soon after (Alden Joy, personal communication, 1977). With the exception of a few large clearcuts established on nearby Weyerhaeuser land after 1974, little clearcutting has been done in the Dead Indian area since 1963.

Observations, Field Trials, and Research Studies

Several formal research studies have been established on the Dead Indian Plateau. In addition, many informal observations have been recorded by fieldworkers performing their management and administrative duties. Both sources of information were used in compiling this summary of investigative work accomplished on the plateau.

ENTOMOLOGY

The first formal research efforts in the area were accomplished by employees of the USDA Bureau of Entomology before World War I. Bureau entomologists from Klamath Falls organized a pine beetle control project at Parker Station, just east of the Dead Indian Plateau, early in 1912. As Parker Station was nearer to Ashland than to Klamath Falls, these entomologists moved to Ashland and established the Ashland Field Station in 1912.[8] Pine beetle surveys and research were conducted from this Ashland station. In addition, a considerable amount of research on cone and seed insects was accomplished from 1913 to 1917 by the entomologists stationed there (Keen 1958). Although not mentioned specifically, the Dead Indian Plateau probably provided much of the biological material used in this early research (Miller 1915, 1916).

Several significant contributions resulted from research on pine beetles on the plateau and around it. Studies by Ashland Station entomologists from 1915 to 1919 led to new proposals for control of beetles that were subsequently tested in several experimental projects.[9] Keen correlated ponderosa pine radial growth and numbers of beetle attacks in the Jenny Creek area between 1917 and 1926 and observed that vigorous tree growth resulted in resistance to attack by bark beetles (Miller and Keen 1960). Patterson studied artificial attraction of beetles and the use of solar heat as a control method in the same area during the summer of 1920. When this solar heat method and a more effective burning treatment were applied in southern Oregon and northern California from 1922 until 1925, a 27-percent reduction in losses caused by western pine beetles resulted.[10]

[7] Alden Joy (Ashland District, Rogue River National Forest), personal communication, 1977.

[8] Keen, F. P. 1972. Why the Ashland, Oregon station? Memorandum on file at Forestry Sciences Laboratory, Corvallis, Oreg. 3 p.

[9] Burke, H. E. 1946. My recollections of the first years in forest entomology. Mimeogr. On file at Forest Sciences Laboratory, Corvallis, Oreg. 37 p., illus.

[10] Keen, F. P. 1925. Analysis of results of control. Southern Oregon-northern California pine beetle control project 1922-1925. USDA Bur. Entomol., For. Insect Invest. Tech. Rep. 2, 21 p. On file at Forestry Sciences Laboratory, Corvallis, Oreg.

Southeastern and eastern portions of the Dead Indian area were surveyed annually for pine beetle damage after 1920.[11/][12/] Infested ponderosa pines probably were felled, peeled, and burned in T. 38 S., R. 5 E., and T. 39 S., R. 4 E., in 1924.[13/] After that, the men carrying out annual pine beetle surveys in and around the Dead Indian area recorded major beetle infestations in 1925-26, 1931, and 1934. The 1933 survey was conducted from a camp at Moon Prairie.[14/]

J. E. Patterson, an entomologist at the Ashland Field Station, utilized the construction of Green Springs Highway to study the influence of line slash on the spread of pine beetles to adjacent uncut timber (Patterson 1927). He found the slash to be very attrative to *Dendroctonus brevicomis*, and beetles from the surrounding timber were temporarily concentrated along the new highway. Brood mortality, however, was abnormally high in the slash and normal distribution of the beetle population resumed within a year. Infestation in the surrounding forests was not increased, and Patterson concluded that infestation by *D. brevicomis* may be disregarded when slash disposal is considered.

The Ashland Field Station was closed about 1925 (see footnote 8), effectively ending most entomological research in the area. Little research seems to have been conducted or recorded there during the next 15 years, and the Dead Indian apparently slept peacefully until the demands of World War II stimulated timber harvest on the plateau.

FOREST REGENERATION

Even during World War II, the initial light selection logging created no serious problems. Soon after the war, however, when regeneration failures began to be conspicuous, local foresters began to compare notes and set up field trials. Researchers eventually arrived after economic selection cutting was replaced by more intensive forestry practices.

A gradual awakening to some of the most serious regeneration problems has been well summarized by BLM forester W. F. Edinger (1973):

> In the true fir forest, on the Dead Indian Plateau south of Mt. McLoughlin, clear cutting was thought by many to be a way to convert old stagnant, uneven-age stands to a thrifty young forest. Over several years, these early cuttings did not reforest naturally. Plantings of true fir and Douglas-fir died. Ponderosa pine survived some of the time. Often, those that made it through the first summer succumbed to pocket gophers or grasshoppers. Sometimes heavy grass and sedge invasion prevented survival due to competition for moisture in summer.... Ground temperatures up to 140° proved lethal to volunteer and planted trees alike. Despite repeated planting and seed spotting, many of these clearcuts are still unstocked twenty years after cutting.... We have learned the lesson that hot, dry summers and low nutrient soils will not permit us to denude the landscape on the

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11/ Jaenicke, A. J. 1921. Statistical data on the western pine beetle situation on the proposed southern Oregon-northern California control project. South. Oreg. north. Calif. proj., vol. A, No. 1. On file at Forestry Sciences Laboratory, Corvallis, Oreg.

12/ Keen, F. P. 1923. Instructions for summer survey of 1923, southern Oregon-northern California pine beetle control project. On file at Forestry Sciences Laboratory, Corvallis, Oreg.

13/ Keen, F. P. 1924. Working plan for fall work, 1924. On file at Forestry Sciences Laboratory, Corvallis, Oreg.

14/ Keen, F. P. 1938. Report of pine beetle surveys of the Keno area, Klamath working circle. USDA For. Serv. Insect Lab., Portland, Oreg. On file at Forestry Sciences Laboratory, Corvallis, Oreg.

Dead Indian unless we can somehow manage to make boards out of gophers, weeds, and elderberry bushes.

Even before extensive clearcutting was begun, attempts to reforest areas denuded by nature in the Dead Indian area sometimes were accompanied by careful measurements of mortality. R. K. Hermann (Oregon State University) and H. Thomas (Rogue River National Forest) published some of these early observations (Hermann and Thomas 1963). In April 1951, a 5.2-acre (2.1-ha) ponderosa pine plantation was established on a portion of the 1910 Moon Prairie burn that reburned in 1917. The 2-0 seedlings were planted 7 feet (2.1 m) apart in 4-ft^2 (0.37-m^2) scalped spots. Part of this early plantation was fenced to keep out livestock, and the area was baited twice with strychnine-treated gopher bait 1 month after planting. A prolonged summer drought in 1951 apparently killed most of the seedlings, for survival was only 25 percent at the end of the first growing season. Subsequent mortality reduced survival in the plantation to 39 of the original 4,700 trees after 11 growing seasons--only 0.9 percent survived. Pocket gophers were the main cause of mortality after the first growing season. Hermann and Thomas observed that gopher damage on the Dead Indian Plateau varied with locality, but most occurred during the winter at high elevations where the snow was deep.

Although detailed records were not kept in every case, ponderosa pines were planted on many open sites during the middle 1950's (Alden Joy, personal communication, 1977). In some of these pine plantations, failure was as spectacular as that reported by Hermann and Thomas. In others, moderate to good survival produced pure young ponderosa pine stands. Unfortunately, most of this early planting stock originated from offsite seed sources. Therefore, most of the surviving plantations only served as nurse crops for natural regeneration. During this period, pine from offsite seed sources was deliberately planted as a nurse crop by the Forest Service at 5,200- to 5,700-foot (1 590- to 1 740-m) elevations in sec. 14, T. 38 S., R. 4 E. Natural regeneration subsequently came in successfully along the edges of the 20-acre (8.1-ha) clearcuts in which this technique was applied, but planting pine from offsite seed sources should be avoided.

Natural regeneration of Shasta red fir was surveyed by H. J. Gratkowski (1958), Pacific Northwest Forest and Range Experiment Station, on four small, high-elevation clearcuts north of Brush Mountain in 1955. Each was 12.5 acres (5.1 ha) in size, and all were cut and slash burned 2 years before the survey. Stocking ranged from 18 to 50 percent of the 4-milacre (0.0016-ha) plots measured--remarkably good for the Dead Indian Plateau. Gratkowski found unburned areas within the clearcuts much more heavily stocked than burned areas. He did not favor artificial regeneration of these high-elevation sites and recommended that clearcut size be limited to 15 to 20 acres (6.1 to 8.1 ha).

During the next few years (1959-62), several BLM silvicultural reports from the Dead Indian area noted that natural regeneration would occur under many partially cut stands if enough time were allowed (see footnote 4). The silvicultural reports also mentioned advance regeneration, often present in sufficient quantity to stock the future stand. Unfortunately, some of these reports were overly optimistic. A 1960 memorandum predicted that a north slope draw in NW1/4 sec. 11, T. 38 S., R. 3 E., could be successfully clearcut "...with the chance of reproduction coming in naturally fairly good," but the clearcut was still not stocked in 1975 (see footnote 4).

Forest Service foresters tried to supplement the natural seed crop in 1961 by helicopter-seeding 40 acres in sec. 3, T. 38 S., R. 4 E. The attempt was a complete failure (Alden Joy, personal communication, 1977). Reforestation problems on the Dead Indian Plateau and progress during the 1958-63 period were summarized in a BLM memorandum by Lawrence, who observed that frost heaving was bad and natural regeneration very slow.

He also noted that "Borrow pits where the A horizon is removed frequently have good pine reproduction, which indicates that we may need to tear up the A horizon more or remove it" (see footnote 6). This observation was reinforced by William Stoate, an Australian working in northwestern California at that time. Stoate visited the Dead Indian Plateau and also suggested removal of the A horizon (Mark E. Lawrence, personal communication, 1977). This was tried shortly thereafter (1964-65) by terracing several clearcut areas along the Conde Creek access road (sec. 17, T. 38 S., R. 3 E.). Gophers killed the planted seedlings on these terraces, and the attempt failed. Several years later, BLM foresters tried to control gophers on the terraces by setting out baits with a tunnel builder, but efficient use of the machine was apparently prevented by rocky soil. Seedling mortality precluded any measurements at Conde Creek, but site deterioration may follow removal of the A horizon.

Seedling mortality also hindered the measurements of Richard K. Hermann, an Oregon State University researcher who set up several experiental plantations on the plateau during the middle 1960's. His initial ponderosa pine plantation was abandoned after 2 years when gophers caused losses of nearly 100 percent. A second study used artificial depressions ("shurfs") to trap moisture, three plowing depths, three species (ponderosa pine, Douglas-fir, white fir), and three stock types (2-0, 2-1, 2-2). Again, losses caused by gophers were so high (above 90 percent) that it was impossible to assess treatment effects. Despite these setbacks, Hermann established a third study in 1964. It involved southwestern Oregon Douglas-fir provenances planted in a fenced clearcut area near the Conde Creek access road (sec. 17, T. 38 S., R. 3 E.). He replanted this last area three times and finally gave up after the trees were consecutively destroyed by grasshoppers and gophers.

D. Minore (1971), Pacific Northwest Forest and Range Experiment Station, artificially shaded recently planted Douglas-fir seedlings north of Moon Prairie by piling logs and/or rocks around them in May 1968. After two growing seasons the survival of these shaded seedlings (60 percent) was significantly better than that of adjacent unshaded seedlings (10 percent) planted at the same time. Seedlings planted under the shade of living shrubs or trees also survived significantly better than those in the open. Shade was essential to survival of Douglas-fir seedlings on this hot, dry site.

Shade requirements probably are influenced by the abundant grass cover commonly found on the Dead Indian Plateau--a grass cover that may be considered either a bane or a blessing, depending on one's viewpoint and management objectives. A recent Pacific Northwest Forest and Range Experiment Station survey of regeneration on the Dead Indian Plateau showed conifer stocking to be poorer on grass-dominated sites than on sites dominated by herbaceous or woody vegetation.[15/] Stein's comments are excellent summaries of the timber management viewpoint. "Development of grass is one of the quickest ways to render a site inhospitable to young trees. Once a site is lost to grass, establishment of trees requires extraordinary effort." He cites examples to show that the cattle which pasture on this grass compound the problem by trampling seedlings and damaging woody perennials that provide cover.

The cattle that trample seedlings also produce the beef needed by our growing population, however, and grazing may not always damage seedlings (Alden Joy, personal communication, 1977). Beef production should not be ignored when grass is considered on the Dead Indian Plateau. Range for deer and other wildlife benefits should also be considered. These factors were evaluated by Forest Service personnel in 1973 after

[15/] Stein, William I. 1978. Regeneration outlook on Bureau of Land Management lands in the southern Cascades. Data on file at Forestry Sciences Laboratory, Corvallis, Oreg.

intensive site preparation eliminated the natural vegetation in many Ashland District stands. They decided that such site preparation resulted in unacceptable forage and wildlife conditions. Accordingly, the District began seeding grass after all shelterwood cutting operations.

Standard Forest Service operating procedure on the plateau from 1973 through 1977 was (Alden Joy, personal communication, 1977):

1. A two-stage shelterwood system was initially cut to leave 100-110 ft^2 of overstory basal area per acre (23-25 m^2/ha).
2. Brush-bladed tractors were used to pile brush, and the seed bed was ripped as soon as possible after the shelterwood cut.
3. A grass seed mixture was broadcast in the fall.
4. Douglas-fir and white fir bare-root seedlings were hoe-planted at 8- by 8-ft (2.4- by 2.4-m) spacing the following spring.

The grass seed mixture broadcast in the fall consisted of 50 percent orchard grass, 44 percent tall fescue, and 6 percent timothy or highland bent. It was applied at the rate of 16 pounds per acre (17.9 kg/ha) from 1973 through 1975. In 1976 and 1977 the amount was reduced to 15 pounds per acre (16.8 kg/ha), and only orchard grass was used. Orchard grass may be planted again in 1978; but only 4-6 pounds per acre (4.5-6.7 kg/ha) will be used, and grass seeding will be deferred until 1 year after tree seedlings have been planted.[16/]

Bureau of Land Management foresters are not applying grass seed in the two-stage shelterwood operations they adopted in 1976. Indeed, in partially cut stands underplanted several years after cutting, one BLM forester believes that newly planted seedlings "don't stand a chance" without scalping or grass control (Larsen's field notes--see footnote 4). Larsen blamed improper seed sources, poor seedling condition after transport to the planting site, lack of adequate site preparation, and/or bad planting technique for the failure of more than half the areas underplanted by BLM foresters in the Dead Indian area during 1975. He observed little difference in the success of spring- and fall-planted Douglas-fir in these partial-cut plantations but found that white fir did best if lifted and planted in the spring.

Larsen's field notes contain many excellent observations and several astute conclusions. He limits the area in which severe regeneration problems occur to that portion of the plateau west of a line drawn from Deadwood Junction to Jenny Creek Spring, thence to the summit of Chinquapin Mountain, then south to the Green Springs Highway; but he notes that mountain summits east of that line have similar problems (gophers and other small rodents, insects, competing vegetation, and frost).

D. M. Williamson (1978), Oregon State University, studied frost and moisture to evaluate factors affecting the survival and growth of planted seedlings on the plateau. He also evaluated the effects of overstory canopy, cattle fencing, rodent caging, planting-stock species, and stock type during this study, which involved four experimental plantations established in 1975. They consisted of bare-root and container-grown seedlings of Douglas-fir, white fir, and ponderosa pine planted on four severe sites on the Dead Indian Plateau. Replicated gopher caging, cattle fencing, and irrigation treatments were applied on each site--half under the canopy of a partially cut stand and half in an adjacent open area.

After two abnormally wet growing seasons, Williamson concluded that frost and pocket gophers seemed to be the most important variables affecting survival and growth of all species and stock types. Average survival under the canopy (88.8 percent) was significantly better than survival in the open (36.4 percent). Minimum growing season

16/ William H. Harbaugh (Ashland District, Rogue River National Forest), personal communication, 1978.

temperatures under the canopy averaged 9°F (5°C) warmer than those in the adjacent open areas, and much less frost damage occurred there. Gopher caging improved survival in the open but not under the canopy--probably because of larger populations of gophers in the open. As expected, survival of ponderosa pine was better than that of Douglas-fir or white fir in the open. Under the canopy, however, survival of species did not differ, and container-grown Douglas-fir and white fir stock grew better than all other stock, regardless of species. Williamson concluded that the presence of an overstory canopy apparently is the single most important factor contributing to plantation success on the Dead Indian Plateau.

Where there is no overstory canopy, frost-resistant planting stock and/or gopher control seem necessary. Lodgepole pine appears to be even more resistant than ponderosa pine to summer frosts on the plateau, and Jeffrey pine seems to resist snow breakage better.[17/] Snow breakage becomes increasingly important as elevation increases, and Forest Service foresters prefer to plant mixtures of Douglas-fir and white fir (and rust-resistant white pine when available) at high elevations, ponderosa pine at lower elevations around Howard Prairie Reservoir (Alden Joy, personal communication, 1977).

W. I. Stein (see footnote 15) surveyed natural and artificial regeneration at both high and low elevations throughout the Dead Indian area in 1973 and 1974 by sampling randomly selected partially cut and clearcut areas logged during the 1956-70 period. He found that total regeneration increased with the abundance of woody perennials and decreased with radiation index (a figure based on slope and aspect) on both partially cut and clearcut areas.

Regeneration of Douglas-fir and true firs decreased as ground cover increased in the clearcuts, but only true firs were adversely affected by ground cover in partial cuts (see footnote 15). Stocking ranged from 5 to 100 percent (average, 65 percent) in the 52 Dead Indian partial cuts sampled by Stein's Pacific Northwest Forest and Range Experiment Station survey crews. Approximately half their stocked 4-milacre (0.0016-ha) plots were dominated by advance regeneration. Stocking ranged from 0 to 75 percent (average, 33 percent) on the 16 clearcuts sampled, but only 4 were at least 50 percent stocked. Most of this clearcut stocking was established after cutting. Stein listed frost, vegetative competition, grazing, and gophers as the primary factors hindering the establishment and growth of forest tree seedlings on the Dead Indian Plateau. His survey data will soon be published.

PATHOLOGY

A 1958 aerial survey of Douglas-fir dwarf mistletoe damage was conducted by Pacific Northwest Forest and Range Experiment Station pathologists. It included the Dead Indian Plateau and was summarized in a progress report.[18/] Flying from north to south along section lines 2 miles (3.2 km) apart, the pathologists identified and mapped areas of light, moderate, heavy, and very heavy mortality. Acreages in each mortality class were determined from the aerial sketch maps. Ground surveys were subsequently accomplished to determine the diameters, mistletoe infections, and risk ratings of sample trees in the mapped areas. Although approximately 12 percent of the old-growth Douglas-fir trees in the Dead Indian area were heavily infected with dwarf mistletoe, no moderate, heavy, or very heavy mortality classes were mapped on the plateau.

Where mistletoe infections occur

17/ Duane Kingsley (Rogue River National Forest), personal communication, 1977.

18/ Aho, Paul E., and Lyle N. Anderson. 1959. Douglas-fir dwarfmistletoe aerial survey, Rogue River National Forest, 1958. Office report on file at Forestry Sciences Laboratory, Corvallis, Oreg. 12 p.

the Forest Service now applies stand cleaning techniques to reduce or eliminate them. In clearcuts threatened by mistletoe, infected residual trees are killed, infected species are eliminated in surrounding stands, and susceptible plantation seedlings are often kept away from the adjoining uncut stand. In shelterwoods, infected species are removed in the first cut, species are mixed in the understory plantation, infected understory trees are eliminated during subsequent thinning operations, and the perimeters of plantations are protected.[19/]

Other forest diseases are often less evident than mistletoe, but they can be just as destructive. Heart-rot fungi are particularly important in mature stands. P. E. Aho (Pacific Northwest Forest and Range Experiment Station) studied these organisms and their effects on the Dead Indian Plateau from 1966 until 1970. He found four to be most important: *Echinodontium tinctorium*, *Phellinus chrysoloma*, *Pholiota adiposa*, and *Hericium abietis*. Dissecting defective trees, Aho identified infection courts (branches and basal wounds), correlated hidden decay with visible defect indicators, and developed two methods for estimating defect in standing white fir trees in southwestern Oregon (Aho 1975). One method uses defect percentage tables based on d.b.h., age, and decay indicators. The second provides average length deductions below and above various indicators, with flat percentage factors for hidden defect. Defect indicators include conks, punky knots, wounds, scars, frost cracks, crooks, forks, mistletoe cankers, dead or broken tops, and dead vertical branches. Defect estimation techniques were summarized by Aho and Roth (1978).

Aho also identified nitrogen-fixing bacteria associated with fungi (Aho et al. 1974) and suggested an important role for these microorganisms in the decay process. Decay should have little effect on selection of future white fir rotation ages.[20/]

RODENTS

Rotation ages become meaningless in areas where gophers destroy the seedlings before a stand can be established. Fortunately, not all areas are seriously affected. Larsen (see footnote 3) divided the problem of pocket gophers into three categories:

1. Light damage is usually found on clay soils or where brush is a rapid invader (e.g., Brush Mountain).
2. Moderate to heavy damage is common where grass constitutes the dominant invading vegetation after timber harvest (e.g., the Conde Creek and Moon Prairie areas).
3. Heavy to extreme damage is found in areas characterized by open glades with abundant lupine, yarrow, and wild pea (e.g., Cottonwood Glades and the summit of Surveyor Mountain).

Larsen believes that foresters "can live" with damage in the first category and can practice vegetative manipulation in the second but that they have few options other than buffer strips and limited direct control in the third category.

Direct control of gophers is laborious and expensive. Baiting is cheaper than trapping, but neither work well where gophers are present in surrounding areas. "The physical job of baiting runways 4 to 8 inches below ground surface over any large area with 50-70 gophers per acre is very demoralizing," and "...the unoccupied burrow systems are rapidly

[19/] Kingsley, Duane. 1978. Dwarf mistletoe control on the Rogue River National Forest in Oregon. Paper presented at the Dwarf Mistletoe Symposium, Berkeley, Calif., April 11-13, 1978, 5 p.

[20/] Aho, Paul E. 1968. Defect in white and red firs on the Rogue River National Forest - 1968. A progress report on file at Forestry Sciences Laboratory, Corvallis, Oreg. 20 p.

reoccupied by invasion from adjacent populations" (see footnote 3).

Direct control of gophers is not always necessary. Deliberate plant community modification to reduce the gophers' food supply in cutover areas was initiated in 1970 by E. F. Hooven.[21] He applied atrazine and 2,4-D to plots in sec. 4, T. 38 S., R. 4 E. This work was expanded in a 1972-76 study by Black and Hooven (1975, 1977) on eight unstocked, 20-acre (8.1-ha) clearcut units in sections 13 and 17, T. 38 S., R. 3 E. They applied four herbicide treatments: (1) atrazine + simazine, (2) 2,4-D, (3) atrazine + simazine + 2,4-D, and (4) spot treatment with atrazine. The spot treatment was applied only once, after a 1972 planting. The other treatments were applied three times, in 1972, 1973, and 1974. Conifer seedlings planted in the fall of 1972 failed to survive, as did those planted in the fall of 1973. The treated plots were planted a third time in November 1974 in five-species clusters of ponderosa pine, incense-cedar, Douglas-fir, white fir, and lodgepole pine. A final five-species planting was accomplished in the spring of 1975. Gopher activity, seedling damage, herbaceous cover, and conifer mortality were monitored annually.

Black and Hooven (1975) also studied the treatment response of small mammal communities. In the clearcuts, these mammal communities contained the following principal species, in order of abundance:[22] deer mouse (*Peromyscus maniculatus*), Great Basin pocket mouse (*Perognathus parvus*), long-tailed vole (*Microtus longicaudus*), yellow pine chipmunk (*Eutamias amoenus*), vagrant shrew (*Sorex vagrans*), golden-mantled ground squirrel (*Spermophilus lateralis*), and Townsend's chipmunk (*Eutamias townsendi*). Except for pocket mice and deer mice, diversity and abundance of small mammals were not markedly affected by herbicide treatment in the clearcuts. (Pocket mice increased and deer mice sharply decreased after herbicide treatment) In the surrounding partially cut stands, pocket mice were absent and deer mice were present in very low numbers. The red-backed vole (*Clethrionomys gapperi*) was abundant in the partial cuts, as was Townsend's chipmunk, but yellow pine chipmunks were absent or scarce.[23]

A detailed report of the Black-Hooven research is being prepared for publication. In general, gopher damage to seedlings was reduced on areas treated with atrazine and simazine. Mortality of seedlings was least where all three herbicides had been applied together. Pines survived better than firs where grass was not controlled, but few seedlings of any species survived competition from uncontrolled grass.

SOIL MOISTURE

Seedling survival often depends on adequate soil moisture. Year-to-year variation occurs, but seasonal trends are evident every year. Larsen (see footnote 3) categorized these trends on the Dead Indian Plateau during "planting season:"

"November-December 10----Moisture only in top 3 inches" (7.6 cm).

"December 11-January 1----Moisture to 6 inches" (15.2 cm), "depends on snow and thaw conditions.

March, April, and May----Soil profile saturated.

May-June----Exposed level or south slopes drying rapidly to 3 inches (7.6 cm).

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[21] Edward F. Hooven (Oregon State University), personal communication, 1977. Mention of pesticides in this publication is for the information and convenience of the reader. Such use does not constitute an endorsement by the U.S. Department of Agriculture. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

[22] The source for scientific names for mammals is Larrison (1976).

[23] Black, Hugh C. 1973. Correspondence with W. R. Smith, Bureau of Land Management, Oregon State Office, June 25, 1973. On file at BLM, Medford District Office, Medford, Oreg.

"July----Beginning of drought.

August, September, and October----Soil like powder to 12 inches" (30.5 cm).

After finding high elevation sites where the soil was just as dry in the spring as in the previous fall despite deep soils and an adequate snowpack, Larsen concluded that freezing soil temperatures before the snowpack builds up can be serious deterrents to subsequent percolation and moisture recharge of the soil profile.

Soil moisture was studied on the plateau in 1965 by William E. Hallin (1968), a research forester from the Pacific Northwest Forest and Range Experiment Station. He sampled soil moisture content, moisture tension, and soil texture at 6-, 18-, and 36-inch (15-, 46-, and 91-cm) depths in three locations in a large cutover area "...to determine whether moisture depletion by vegetation was great enough to be a factor in planted tree mortality." Hallin removed vegetation from one 10-foot (3-m) square area with a hoe and used a tractor-pulled plow to furrow the second location; he left the third location undisturbed. Six inches (15 cm) below the surface, the undisturbed soil sample had 100 times more soil moisture tension than either the hoed or furrowed samples by the last week in July. At the 18-inch (46-cm) depth, moisture tension was approximately seven times greater in the undisturbed location. Soil moisture tension of approximately 15 atmospheres constitutes the moisture content at which permanent wilting occurs in most soils (Bonner and Galston 1952, p. 144). As soil at the undisturbed location reached a tension of 101.7 atmospheres at 6 inches (15 cm), moisture depletion by vegetation was great enough to affect mortality of planted trees in the sampled cutover. Hallin recommended planting or seeding immediately after harvest cutting, before competing vegetation becomes established. Alternatively, established vegetation could be removed or killed before establishment of forest regeneration is attempted.

COMPETING VEGETATION

Removing or killing the competing vegetation in Dead Indian clearcuts was accomplished in several ways during the 1964-70 period. With Hallin's help, the Forest Service set up a trenching program for Ashland District clearcuts. An AC-24[24] tractor with construction ripper teeth and a double moldboard plow held in the ground by 1,400 pounds (635 kg) of hydraulic pressure were used to construct furrows 2 feet (0.6 m) deep and 3 feet (0.9 m) wide (Alden Joy, personal communication, 1977). After lying fallow for 1 year, the furrows were planted at an 8-foot (2.4-m) spacing. Snow collected in the furrows, and there was 38 percent more moisture in the furrows than under the adjacent grass when soils were sampled in July (Alden Joy, personal communication, 1977). The trenching operation cost approximately $40 per acre ($98 per ha) in 1965.

Approximately 600 acres (243 ha) were trenched in Forest Service clearcuts on the plateau. In addition, the Medco Company trenched some of their land in the area. Trenching succeeded where pocket gophers were not a problem. Unfortunately, most areas on the plateau are plagued by gophers. Baiting the trenched areas helped some, but gophers continued to cause severe damage until surviving furrow-planted trees were waist high on most sites. The furrowing apparently was completely successful only where gophers were not present in adjacent areas. In one of these successful areas (sec. 3, T. 38 S., R. 4 E.), alternate rows of lodgepole and ponderosa pines were planted in the trenches. Both species survived and grew similarly in this Forest Service trial (Alden Joy, personal communication, 1977).

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[24] Mention of companies and products by name is for the information and convenience of the reader and does not constitute an endorsement by the US Department of Agriculture to the exclusion of other products which may be suitable.

A somewhat different method of removing vegetation was used by Boise-Cascade Company foresters during the late 1960's. They scarified many areas by blading off the grass in strips with a tractor. This scarification treatment apparently was successful in controlling grass, but gophers seem to have destroyed all the seedlings subsequently planted.

After this discouraging experience with scarification, Boise-Cascade foresters began using atrazine to control the serious grass competition in the Dead Indian area. Their initial preplanting spring applications often were unsuccessful. Snowpacks sometimes lingered until quite late in the spring on the plateau, and subsequent rainfall was insufficient to wash in the chemical after spraying could be done. Spraying atrazine after planting also seems to have been unsuccessful. Gophers probably ate the planted seedlings the following winter. Boise-Cascade now sprays with atrazine in the fall, then plants the sprayed areas 1 year after the following spring--successfully.

SITE CLASSIFICATION

Successful results obtained on one site often are not applicable to other sites on the Dead Indian Plateau. Soil variation may be responsible. In 1969 the Oregon State Water Resources Board published general soil map reports for the Klamath (Cahoon and Simonson 1969) and Rogue (Power and Simonson 1969) drainage basins. Including soil series descriptions as well as general soil series maps, these publications provided a general orientation for foresters comparing the soils on different parts of the Dead Indian Plateau. They also provided useful documentation for the observations of men like M. E. Lawrence, who had long noticed that regeneration problems were much less serious east of a soil change that occurs around the summit of Keno Road above Moon Prairie (Mark E. Lawrence, personal communication, 1977). More detailed soil maps were published by the Bureau of Land Management (deMoulin et al. 1975) and the Weyerhaeuser Company (Duncan and Steinbrenner 1975) several years later. Unfortunately, Weyerhaeuser's superb soil survey did not include all the Dead Indian Plateau.

A vegetation survey of the plateau was accomplished during the 1967-76 period by O. E. Hickman; although not published yet, it is a study of vegetative classification and geographical distribution of plant communities in the area.[25]

D. Minore and R. E. Carkin (1978), Pacific Northwest Forest and Range Experiment Station, studied vegetation, soils, overstory canopy, and natural regeneration in the Dead Indian area from 1973 through 1976. They measured 17 environmental variables, then used stepwise multiple regression analyses in relating them to postharvest natural regeneration on 55 partially cut areas. Total soil nitrogen, overstory canopy density, and vegetation were significantly correlated with natural regeneration stocking percent. The nitrogen correlation was negative--perhaps as a result of frost sensitivity induced by soil fertility. All other things being equal, optimum canopy density for natural regeneration was 60 percent. A vegetation index derived from the species present was well correlated with natural regeneration in the sample stands, and Minore and Carkin used it to separate the sites needing underplanting from those that did not. They concluded that 80 percent of the stands on the Dead Indian Plateau require underplanting.

Regardless of the management technique applied, some plateau areas are more difficult to regenerate than others. For example, comparison of the natural regeneration stocking recorded by Minore and Carkin (1978) with the soil series mapped by Cahoon and Simonson (1969) and Power and Simonson (1969) revealed several soil-regeneration relationships. Natural regeneration tended to be

[25] O. Eugene Hickman (Soil Conservation Service), personal communication, 1977.

poor on the Pokegama, (Ho), and (Ta) series. It was somewhat better on Woodcock soils, but Oatman soils seemed to have the best natural regeneration.

STAND AGE AND STRUCTURE

Data on stand age and structure were collected by Minore and Carkin in 1976 but not published in their 1978 research note. Overall, their age measurements on the plateau indicate that the mixed conifer forest on the Dead Indian Plateau is uneven aged; trees of every age are present in an age distribution reminiscent of the all-aged stands pictured in silviculture texts (fig. 5). With the exception of a few even-aged stands (e.g., the 50- to 70-year-old white fir-Douglas-fir stand on Chinquapin Mountain), individual sample stands also were uneven aged when considered as separate entities (fig. 6). The average within-stand age range was 301 years.

The uneven-aged nature of these forest stands indicates that most of them did not originate after severe fires or other catastrophes. Neither has regeneration been the result of particularly favorable climatic conditions. Almost every year, regardless of climatic fluctuation, a few seedlings seem to have become established. Regeneration on the Dead Indian Plateau seems to be a slow, steady process rather than a rapid, intermittent one. Under natural undisturbed conditions, the uneven-aged forest replaces itself slowly and evenly, perpetuating an unevenage distribution.

As one would expect when the understory trees experience varying degrees of suppression, age-diameter relationships are quite variable in the Dead Indian area. White fir poles, 4- to 6-inch (10- to 15-cm) d.b.h., varied from 45 to 134 years old in Minore and Carkin's measurements. Douglas-fir and incense-cedar did not vary as much but displayed a considerable age range within each diameter class. Surprisingly, all three species responded vigorously when released from suppression by stand thinning operations--at almost

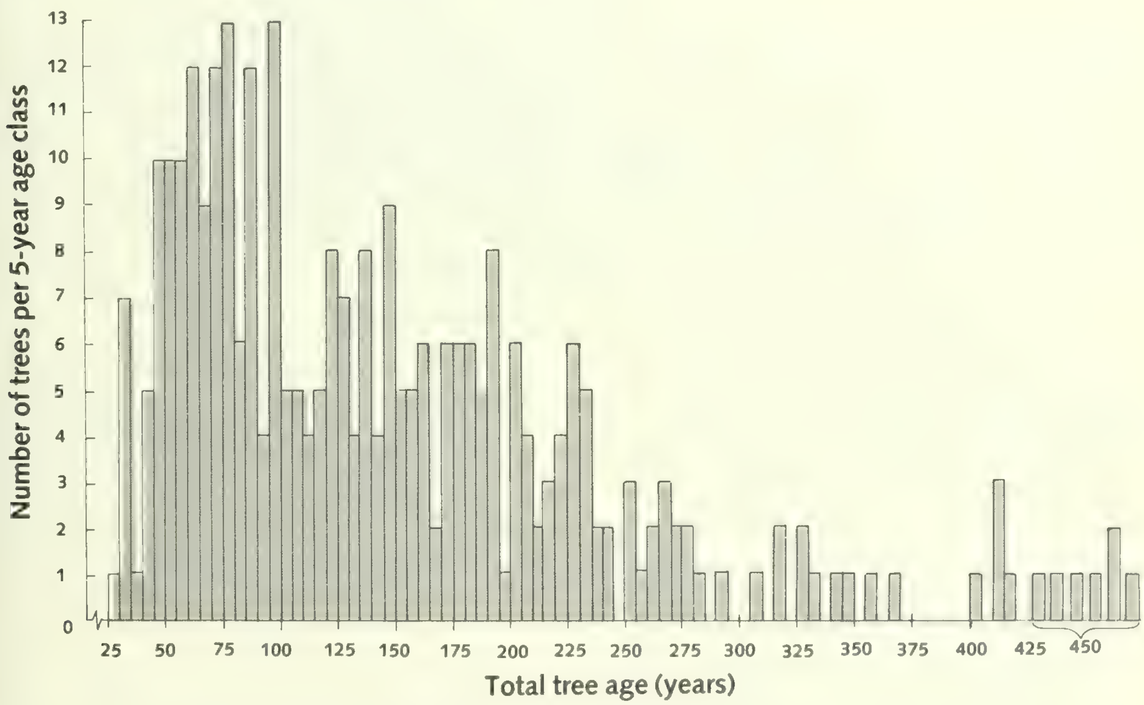

Figure 5.--Age distribution of 300 randomly chosen trees on the Dead Indian Plateau, all species.

Figure 6.--A typical uneven-aged mixed conifer stand after partial cutting. Tree ages vary even more than their sizes indicate.

all ages. Slow-growing, suppressed white firs, Douglas-firs, and incense-cedars up to 200 years old immediately formed much wider annual growth rings after surrounding trees were thinned by partial cutting. Trees of all ages--even large sawtimber trees--respond well to stocking reductions in the Dead Indian area.

Variability in age-diameter relationships could produce diameter distributions that are more uniform than age distributions (young and old trees might have similar diameters). To find out, I constructed a frequency distribution for 1,736 sample diameters tallied on the plateau during 1976 (fig. 7). If a curve is plotted over the bar tops shown in figure 7, an inverted J shape is produced--a shape almost identical to that presented in textbooks as the theoretical distribution of diameter classes in a managed uneven-aged selection forest. Similar diameter distributions result when individual species are considered separately.

Some of the regeneration difficulties experienced by forest managers on the Dead Indian Plateau may result from applying even-age management techniques and expectations to an uneven-aged forest. Where acceptable natural regeneration is anticipated and underplanting is unnecessary, the uneven-aged stands probably should be maintained by selective cutting.

WORK IN PROGRESS

Tractor logging often creates a compaction layer 4 to 6 inches (10 to 15 cm) below the surface of some loose, structureless soils west of Moon Prairie. Farther east, the soils tend to have more structure and are less subject to significant compaction.[26] Seedling roots pene-

[26] Observations of S. Shade (Medford District, BLM), as recorded by L. Larsen (see footnote 3).

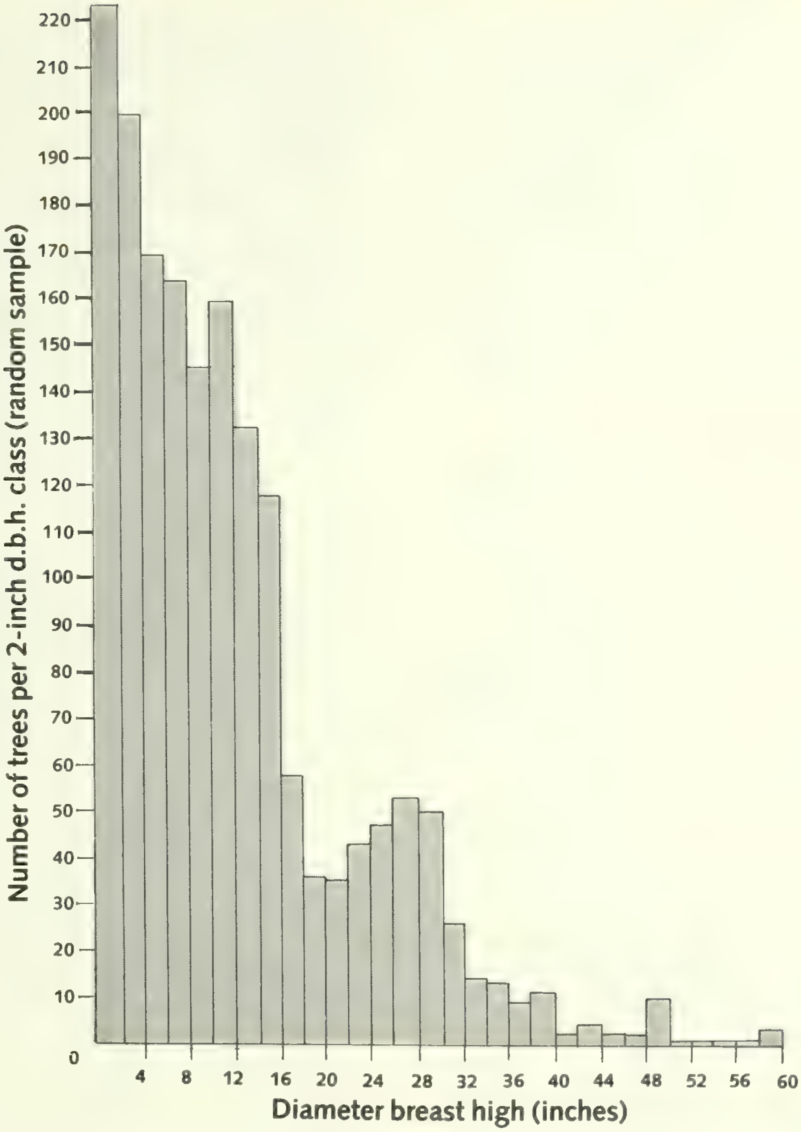

Figure 7.--Diameter distribution of 1,736 sample trees on the Dead Indian Plateau, all species.

trate compacted layers with difficulty, and these layers constitute a deterrent to regeneration. Attempting to ameliorate this condition, the Bureau of Land Management tractor-ripped portions of the previously terraced Conde Creek area in 1977. Results have not been evaluated.

Lodgepole pine plantations may soon be evaluated by Boise-Cascade foresters. Apparently, they hope to reforest frost pockets with the frost-tolerant lodgepole, then get natural regeneration of other species under the resulting cover. The Boise-Cascade foresters have obtained lodgepole pine seeds from plateau sources and are now growing their own planting stock.

Seed collection began on the plateau in 1976 for a study of Douglas-fir breeding zones in southwestern Oregon--a cooperative study involving BLM, Oregon State

University, and the Pacific Northwest Forest and Range Experiment Station.[27] Elevation, latitude, distance from the ocean, aspect, slope, shade profile, vertical distance from the drainage bottom, and vertical height of the major slope on which it is located were recorded at each collection site. The purpose of the study is to provide a practical guide for use in moving seed and for delineating seed zones. This 10- to 12-year study will involve the establishment and monitoring of plantations in 120 locations.

Although most Weyerhaeuser Company research is concentrated in locations east of the plateau, company researchers established several small ponderosa pine-white fir species trials on the Dead Indian Plateau in 1975.[28] A Weyerhaeuser-Boise-Cascade cooperative study near Conde Creek involves the testing of strychnine-oat gopher baits encased in plastic sacks to prevent moisture deterioration.

Conclusions and Recommendations

Several generations of careful observation and research have shown that it is difficult to secure satisfactory forest regeneration on most of the Dead Indian Plateau. Although limiting factors vary among individual sites and differ from year to year, three negative influences seem to be responsible for this poor regeneration: pocket gophers, frost, and the moisture stress produced by vegetative competition. Partial solutions have been devised for each of these problems, but none of the problems have been eliminated.

As normally practiced, clearcutting produces severe regeneration problems on the Dead Indian Plateau. Even small clearcuts remain poorly stocked for years. Intensive site preparation to remove all competing vegetation followed by efficient gopher control and the planting of carefully grown ponderosa pine planting stock of local origin seems to be succeeding where applied by Weyerhaeuser foresters east of the plateau. Their techniques probably would work just as well throughout the Dead Indian area wherever pine monoculture is desired. Replacing the native white fir-Douglas-fir mixed conifer forests with pure ponderosa pine might create unforeseen problems, however, and to attempt large-scale forest type conversion now would probably be unwise.

The many old, unstocked clearcuts on the Dead Indian Plateau should be restored to productive forest stands before any new forest type conversions are attempted. Repeated applications of herbicides (simazine, atrazine, and 2,4-D) to control competing vegetation and reduce the gopher population, followed by the planting of a frost-tolerant tree species (e.g., lodgepole pine) seems to be the best available method. Subsequent gopher baiting may be necessary on some sites. Where frost-sensitive trees are planted in these open clearcuts, additional cover (artificial shading, nurse crops, etc.) should be provided.

Cover is available under partial cut stands. Natural regeneration is rapid in a few of these stands, and an initial cut that leaves an overstory canopy of 60 percent should result in abundant understory seedlings. As an overstory of 60 percent is difficult to remove all at once without damaging established regeneration, individual tree selection and the maintenance of an uneven-aged stand may be desirable in these rapidly regenerating stands. They may be identified before cutting by examining the vegetation and referring to the vegetation index published by Minore and Carkin (1978). Unfortunately, natural regeneration in most Dead Indian stands is too slow to be practical. Underplanting is necessary if a new stand is to be establishe

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[27] Campbell, Robert K. 1977. Delineation of breeding zones for Douglas-fir in southwestern Oregon. Study plan on file at Forestry Sciences Laboratory, Corvallis, Oreg. 9 p.

[28] David Russel (Weyerhaeuser Company), personal communication, 1977.

in a reasonable time period. Container-grown white fir and Douglas-fir planting stock seem appropriate for these underplanting operations.

Continued research and careful observation are essential for progress in forest management on the plateau. Our present knowledge, though useful, provides as many questions as it does answers. For example, we now know that an overstory canopy of 60 percent probably is optimum for natural regeneration, but we do not know the minimum overstory cover that is required to prevent frost damage to underplanted seedlings.

Any overstory canopy cover, optimum or minimum, has to be removed sooner or later. Can this be done without eliminating the understory regeneration? If so, how and when? The initial shelterwood cut and subsequent removal of the overstory will probably compact the soil. Will this soil compaction reduce site quality? If it does, what can be done to prevent or reduce the compaction?

With or without soil compaction, what species or species combinations should be managed on the variety of sites available to the Dead Indian land manager? Which will produce the most timber? Should grazing and timber production be combined on the same multiple use areas or separated? If combined, how can they best be coordinated to produce both beef and boards?

All the above questions should be answered, but they certainly do not constitute a complete or final list. A final list is nearly impossible, for future problem solving will produce further questions. The process, like life, is an unending cycle of temporary setbacks and new beginnings. Viewed in this light, the Dead Indian Plateau seems to have been poorly named. Characterized by controversy, struggle, and achievement, it is an area with many lifelike attributes. If past and present observations, field trials, and research studies are used as criteria, the plateau is not dead but very much alive.

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Experiment Station
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Documentation of Meteorological Data from the Coniferous Forest Biome Primary Station in Oregon

R. H. Waring
H. R. Holbo
R. P. Bueb
R. L. Fredriksen

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service
Portland, Oregon

Abstract

As part of the International Biological Program, a primary meteorological station was installed in the west-central Cascade Range of Oregon. Short-wave solar radiation, air temperature, dewpoint temperature, windspeed, and precipitation are recorded continuously. Climatic data are summarized in a daily record available from May 11, 1972, to date. This report details the measurements, processing, and analyses of these variables at the H. J. Andrews Experimental Forest.

KEYWORDS: Climatography, meteorology, Oregon (H. J. Andrews Experimental Forest).

Authors

R. H. WARING, H. R. HOLBO, and R. P. BUEB are with the School of Forestry, Oregon State University, Corvallis. R. L. FREDRIKSEN is with the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service.

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Introduction

As part of the International Biological Program, the National Science Foundation supported research on the structure and function of coniferous forest. In 1969, the H. J. Andrews Experimental Forest was selected for intensive study by the Coniferous Forest Biome because the 6 075-hectare forest represents diverse forest communities and stream systems characteristic of the central Cascade Range in Oregon. Through the program, both Forest Service and university scientists study processes controlling water, carbon, and mineral distribution in forest and aquatic ecosystems. The participating scientists selected five primary climatic variables affecting the rates at which materials accumulate or move through ecosystems: (1) solar radiation, (2) air temperature, (3) dewpoint temperature, (4) windspeed, and (5) precipitation. This report details the measurement, processing, and analyses of these variables at the H. J. Andrews Experimental Forest. Previously the Pacific Northwest Forest and Range Experiment Station of the U.S. Forest Service collected valuable streamflow data and records of precipitation, air temperature, and relative humidity in the Andrews Experimental Forest. This information is now supplemented by data collected at the primary meteorological station maintained at the forest.

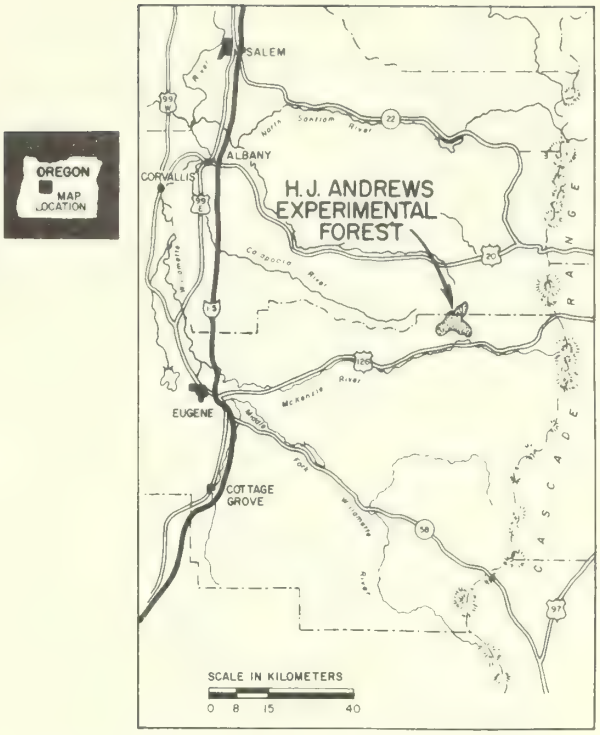


Figure 1.--Map of the H. J. Andrews Experimental Forest, the western Cascade Range of Oregon, and the major rivers draining westward into the Willamette Valley.

Site Description

Located in the central part of the Oregon Cascades (fig. 1), the H. J. Andrews is about 64 km east of Eugene (lat. 44°15'N., long. 122°10'W.). The forest occupies a rugged mountain basin. Elevation ranges from 420 to 1 630 m, and mountain slopes are generally steep with gradients between 20 and 60 percent. Stream drainages are dendritic and deeply incised.

Vegetation typifies the west-central Cascades with extensive Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and hemlock (*Tsuga heterophylla* (Raf.) Sarg.) communities at lower elevations and subalpine forests, characterized by abundant silver fir (*Abies amabilis* (Dougl.) Forbes), at elevations above 1 000 m. Table 1 summarizes the distribution of broad age classes within the major vegetation zones.

Table 1--*Vegetation zones and broad age classes (by percentage) of the H. J. Andrews Experimental Forest and notes on dominant species*

Zone	Forest condition classes			Nonforested communities
	Cutover stands[1/]	Mature forest[2/]	Old-growth forest[3/]	
Temperate forest or *Tsuga heterophylla* Zone	Successional stands of herbs, shrubs, and tree seedlings	Dominated by *Pseudotsuga menziesii;* minor amounts of other species	Dominated by *Pseudotsuga menziesii, Tsuga heterophylla,* and *Thuja plicata*	Narrow riparian or flood plain zones; rock outcrops
60 percent	15 percent	10 percent	35 percent	<1 percent
Subalpine forest or *Abies amabilis* Zone	Successional stands of herbs, shrubs, and tree seedlings	*Abies procera* dominant, but greater mixture of other species (*Pseudotsuga menziesii, Abies amabilis, Pinus monticola,* and *Tsuga mertensiana*)	Mixtures of *Abies procera, A. amabilis, Tsuga heterophylla, T. mertensiana,* and *Psuedotsuga menziesii*	*Alnus sinuata* thickets (3 percent), mountain meadows of various types (2 percent), and rock outcrops (<1 percent)
40 percent	5 percent	15 percent	15 percent	5 percent
Percent of H. J. Andrews in each condition class	20 percent	25 percent	50 percent	5 percent

1/ Clearcuts and shelterwood cuttings are from 1 to 25 years in age.

2/ Mature forest stands are mostly 100 to 150 years in age.

3/ Old-growth stands are stands dominated by trees more than 250 years old.

The vegetation has been detailed by Dyrness et al. (1974).

Soils, poorly developed morphologically, may rest on deep deposits of weathered and unconsolidated parent material. Generally very porous, the soils prevent overland flow of water. Originally described as belonging to the Regosol, Lithosol, Reddish-Brown, and Acid Brown forest soils groups[1/] (Rothacher et al. 1967), most of the soils now are classified as Incepticols with a few Alfisols (Soil Conservation Service 1975). For more information, see Brown and Parsons who used the latter classification.[2/]

Wet, relatively mild winters and dry, cool summers characterize the climate of the experimental forest (figs. 2 and 3), according to U.S. Forest Service records since 1952 from elevations between 400 and 1 000 m. At the meteorological station, temperatures range from -15°C during unusually cold winters to more than 40°C for brief periods almost every summer. Annual temperatures average 9.5°C; the January mean is 2°C and July, 22°C.

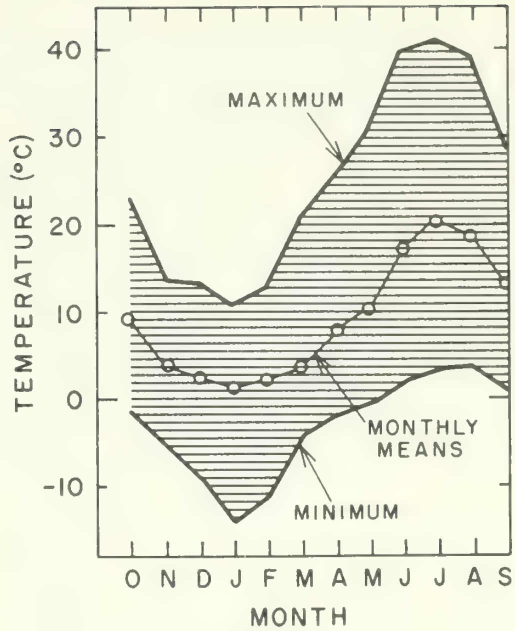
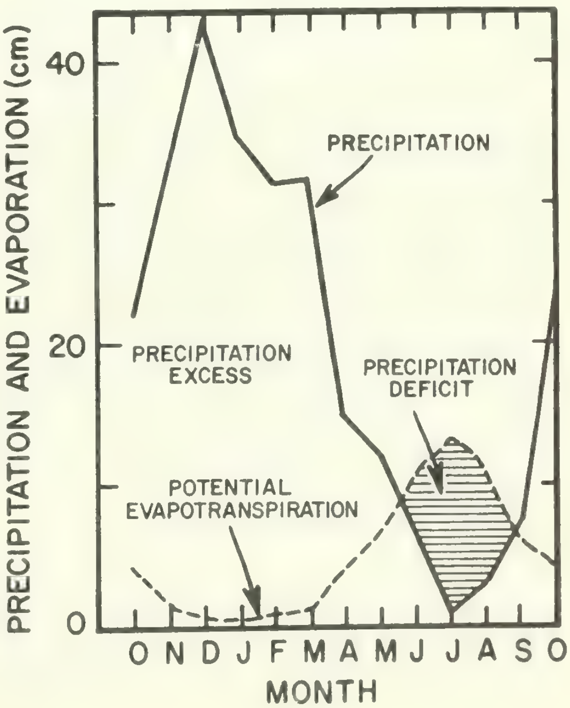


Figure 2.--Typical monthly temperatures at an elevation of 600 m in the H. J. Andrews Experimental Forest.

Figure 3.--Characteristic pattern of precipitation and potential evapotranspiration on the H. J. Andrews Experimental Forest.



1/ U.S. Department of Agriculture, Forest Service. 1964. Soil survey report of the H. J. Andrews Experimental Forest, Willamette National Forest. 52 p. USDA For. Serv., Portland, Oreg.

2/ Brown, R. B., and R. B. Parsons. 1973. Soils of the reference stands--Oregon IBP. Coniferous For. Biome Intern. Rep. 128, 76 p. Univ. Wash., Seattle.

Annual precipitation averages 240 cm; more than 70 percent occurs from November through March; only 7 percent falls during the growing season (fig. 3). Most precipitation in this area results from warm, moist airmasses that move in from the Pacific Ocean. As the airmasses rise over the Cascade crest, prolonged periods of rain may occur. The longest single storm on record (December 18-20, 1957) produced 31.8 cm of rain in 3 days, with a maximum of 15.9 cm in one 24-hour period. A total of almost 70 cm fell during two consecutive major storms in December 1957. In contrast, the months of July, August, and September may be entirely rain free; periods of 60 days without rain are common.

The pattern of maximum temperatures and minimum precipitation during summer months creates a water deficiency. Computed from Thornthwaite's table (Thornthwaite 1948, Thornthwaite and Mather 1957), the difference between potential and actual evapotranspiration ranges from 59 to 11 cm per year. Estimated average evapotranspiration is 54 cm.

Relative humidity, generally high throughout the winter, typically approaches 100 percent each night throughout the rest of the year except when dry air moves west from the high desert east of the Cascade Range. Then minimum relative humidity, generally ranging from 40 to 50 percent during the summer, drops to 10 percent or less. In the winter, extremely low temperatures associated with dry air flowing in from the east considerably reduce the air's capacity to hold water vapor.

Elevation markedly affects precipitation, especially winter snowpack. In the subalpine zone, precipitation shows the same seasonal pattern of wet winters and dry summers. Total precipitation, ho- ever, increases with elevation an totals 30 to 40 percent more at 1 500 m than at 600 m and approac 400 cm annually in some places (U Army Corps of Engineers 1956). F thermore, much of that precipitat equivalent to 100 to 180 cm of wa accumulates in snowpacks as deep 5 m in the subalpine forest. In general, temperatures also decrea with elevation so a permanent win snowpack occurs above 1 000 to 1 20 below those elevations, snow cove is sporadic, developing during co periods and disappearing during warmer winter weather.

Elevational changes in tempe ture are complex, varying with season and the particular tempera characteristic; e.g., mean day or night temperature, diurnal range, maximums, and minimums.[3] Subalp stands above 1 200 m have daily means near -2° to -4°C in midwint and 13° to 16°C in July. A mid-elevation thermal belt results in warmer winter minimums at higher elevations and cooler minimums at lower elevations. In fact, as elevation increases to 1 100 m, average daily minimum temperatures in July also increase because of cold air drainage (see footnote 3).

[3] Zobel, D. B., W. A. McKee, G. M. Hawk, and C. T. Dyrness. 19 Variation in air and soil temperat in forest communities on the H. J. Andrews Experimental Forest, 1970-1972. Coniferous For. Biome Inter Rep. 127, 43 p. Univ. Wash., Seat

At a depth of 20 cm, soil temperatures range from summer maximums of 15^{o} to $20^{o}C$, depending on elevations and site; they drop to winter minimums of $0^{o}C$ at all sites. Largest differences between sites exist in spring when the temperatures at sites retaining a snowpack lag behind those where snowmelt is complete. Soil rarely freezes, mainly because of the insulating snowpack.

The Meteorological Station and Its Operation

The primary meteorological station, generally accessible year round is located on an alluvial terrace at an elevation of 430 m. The immediate area 100 m or more in all directions from the station has been cleared of trees. Solar radiation and wind are measured on a 2-m boom located 5 m above ground on the south side of a tower. Air temperature and dewpoint temperature sensors are located inside a standard meteorological shelter 1 m above ground. A standard precipitation collector located 18 m up the tower funnels precipitation into a large, covered storage tank buried in the ground. These measurements have been compared with the sum of daily measurements taken by the U.S. Forest Service at an adjacent site 0.2 km away.

Originally the battery-powered station was serviced monthly. Because of equipment malfunctions (table 2), more frequent servicing has recently been instigated, but data still are occasionally lost. Furthermore, the sensors differ in their dependability. Table 2, indicating equipment failures since the station was established in 1972, shows that temperature sensors are most reliable and that radiometers and dewpoint sensors require careful attention. The extensive data missing in 1973 reflect instrument failure and an administrative shift in the responsibility for maintenance of equipment.

Table 2--*Days with missing data for three meteorological variables measured from 1972 through 1975*[1]

Year and day	Solar radiation[2]	Air temperature[3]	Dewpoint temperature[4]
1972:			
269-270			X
287-306			X
322-340			X
341-344	X	X	X
345-359	X		X
360-366			X
1973:			
3-12	X		X
13-86			X
121-129			X
130	X		X
131-133	X	X	X
144			X
163			X
167-168			X
176	X	X	X
195-200		X	X
220-224	X	X	X
225-306			X
307-319	X		X
320-348	X	X	X
349-365	X		X
1974:			
1-11	X	X	X
12-73	X		X
96-101			X
105-106			X
136-140			X
161			X
308		X	X
1975:			
79-100			X
131-139			X

[1]X represents days when equipment failed and data are missing.

[2]Missing solar radiation data were estimated from correlations with diurnal fluctuations in temperature during a given month.

[3]Missing temperature data were supplied from a nearby secondary station.

[4]Missing dewpoint temperature data were estimated from correlations with average night temperature.

Procedures such as checking to make sure that no water is inside the radiometer and that desiccant is fresh greatly extend the operation

and accuracy of the instruments. Periodic calibration and servicing of equipment are also essential. Better maintenance (especially of the batteries), the installation of a backup station, and more frequent inspection of the records by knowledgeable personnel substantially reduced the amount of data missing in 1975. A number of temporary stations are operated to permit extrapolation of data from the primary station.

Measured Meteorological Variables

So that data records can be accurately synchronized, at exact 1-hour intervals, a central clock simultaneously interrupts the trace on the recorders for four of the five measured variables--solar radiation, air temperature, dewpoint temperature, and wind. Only precipitation is recorded without interruption.

SOLAR RADIATION

Incoming short-wave solar radiation is measured with a Lintronic dome solarimeter.[4/] Use of a desiccant and periodic calibration generally keep the instrument's accuracy within 10 percent. Photosynthetically active radiation (wavelength of 400 to 700 nanometers) important for primary production can be estimated by assuming that approximately 47 percent of the incoming short-wave solar radiatic is in this spectrum.

An empirically determined heating coefficient (Gay 1971) can be used to estimate net radiation if the long-wave reflectivity or reradiation of the surface--whethe forest canopy, soil, or snow--is known. For Douglas-fir, net radiation is about 65 percent of the measured daily total solar radiati This means that, on a day recordin 650 cal cm^{-2}, the net radiation on a horiztonal surface having the reflectivity of a coniferous fores is 422 cal cm^{-2}. Of this, about half normally is dissipated by evaporating water. Because about 580 cal are required to evaporate a cubic centimeter of water, evapotranspiration rarely exceeds 0.5 cr of water without additional energy supplied by advection (drier or hotter air from another area).

On different slopes and aspects, solar radiation can be estimated with trigonometric calculations (Buffo et al. 1972, Buelow 1967). By this technique, total daily potential solar radiation at any location can be estimated and shading effects by topography corrected.

The solarimeter signal is recorded continually on a 30-day RUSTRAK strip chart scaled from 0 to 2.0 cal cm^{-2} min^{-1} and with a resolution of 0.1 cal cm^{-2} min^{-1}. The signal was damped to maintain chart readability during unsettled conditions.

[4/] Mention of products by name is for the convenience of the reader and does not constitute an endorsement or approval by the U.S. Department of Agriculture or Oregon State University to the exclusion of other products which may be suitable.

AIR TEMPERATURE

Temperature, measured by a thermistor, is continuously recorded on a separate 30-day RUSTRAK strip chart scaled from -10° to 40°C and with an accuracy and resolution of 1°C.

DEWPOINT TEMPERATURE

Water vapor concentration in the air is directly measured with a heated lithium-chloride dewpoint sensor. The sensor temperature, measured with a thermistor, is recorded continually on a separate 30-day RUSTRAK strip chart scaled from -5° to 20°C and with an accuracy and a resolution of 1°C.

WINDSPEED

A cup-type anemometer provides a contact closure for every 0.322 km of air movement. This signal is recorded by an event marker along the border of the same RUSTRAK strip chart used to record dewpoint temperatures. All the RUSTRAK strip charts are housed as an integral unit within the shelter at the primary meteorological station.

PRECIPITATION

Precipitation is recorded continuously by a universal weighing-type rain gage located 0.2 km from the meteorological station. This is the location of the U.S. Forest Service meteorological station still maintained by that agency.

The gages are serviced weekly and more frequently during storm periods. Periodic calibrations are made by weighing the precipitation caught in the 60-cm capacity storage gage. Oil is added to prevent evaporation during the warm seasons and ethylene glycol to prevent freezing during the winter. Daily precipitation recorded on the gage is keypunched onto data summary sheets.

Data Processing and Summarizing

The strip charts are collected at 30-day intervals and forwarded to Biome headquarters at Oregon State University for processing and summarizing. Hourly averages estimated from the strip charts are recorded for keypunching (fig. 4). The keypunched data are printed and checked by the senior author to assure that dewpoint temperatures never exceed air temperatures and that radiation and temperature follow normal patterns throughout the day. Extremes are checked and, if at all unusual, compared with data from secondary stations.

The decks of punched cards record hourly data except the precipitation data provided by the Forest Service, which are summarized for 24-hour periods starting at midnight. All cards are stored in the Biome data bank at the Forestry Sciences Laboratory of the U.S. Forest Service in Corvallis.

The input data for a day are contained on six sequential cards--4 hours of data per card. Each day's deck of hourly radiation, temperature, and dewpoint is analyzed by computer to yield daily averaged data. The computer program is listed in the appendix, and a flow chart is presented in figure 5.

CLIMATIC DATA
H. J. Andrews Experimental Forest
Rainfall 0.00

Year	Day	Hour	Radiation	Air temperature	Dewpoint	Windspeed
74	219	1	0	6	2	2
		2	0	5	2	3
		3	0	4	1	1
		4	0	4	1	2
		5	0	4	1	2
		6	1	5	2	0
		7	4	11	7	0
		8	7	14	10	3
		9	9	20	10	7
		10	10	23	10	7
		11	10	25	10	7
		12	10	26	11	8
		13	10	27	11	7
		14	9	27	8	5
		15	7	27	6	4
		16	1	25	6	5
		17	0	20	7	0
		18	0	16	7	1
		19	0	14	6	4
		20	0	13	6	3
		21	0	11	5	4
		22	0	9	5	3
		23	0	8	5	2
		24	0	8	5	2

Figure 4.--Example of digitized, hourly climatic data prepared for keypunching.

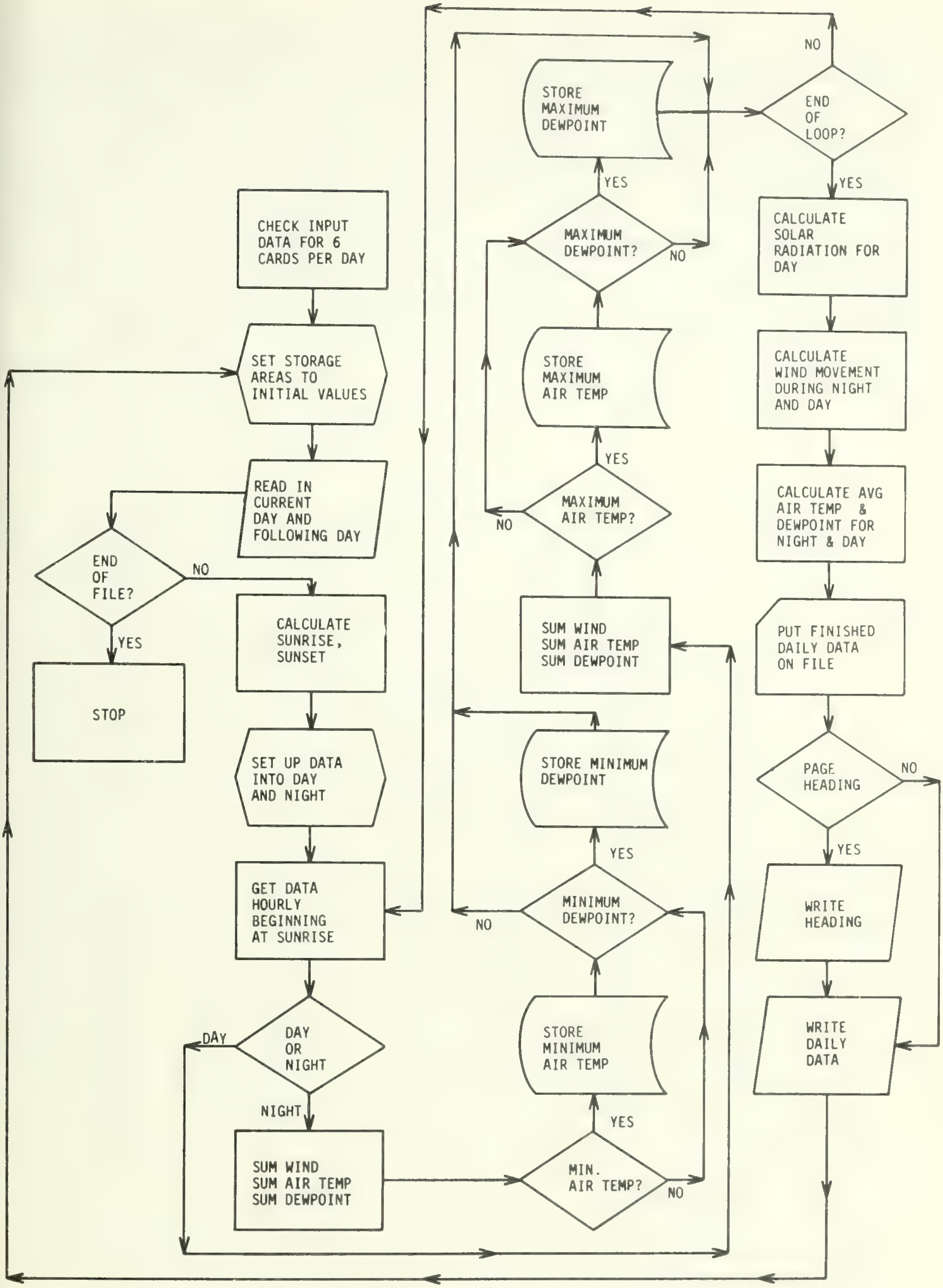


Figure 5.--Flow chart for reducing hourly data to daily summary.

Sunrise, sunset, and day length are calculated from sinusoidal functions listed in the program.

The computer program next separates the hourly data into diurnal and nocturnal segments, beginning with sunrise on the first Julian day and ending with sunrise the next day (table 3). During the two periods, the values for air temperature, dewpoint, and wind movement are summed for each hour in the respective period. The computer program keeps track of the maximum air and dewpoint temperatures duri the day and of the minimum values during the night.

Air and dewpoint temperatures for each daytime or nighttime peri are averaged by dividing the summe values by the number of hours in t period. Wind movement is summed f the period but not averaged. Sola radiation is also summed for the daylight hours.

The computer program compiles file for a card-punched output and

Table 3--*Calendar and Julian dates as used in data analysis*[1/]

Day of month	Jan. 1	Feb. 1	Mar. 3	Apr. 4	May 5	June 6	July 7	Aug. 8	Sept. 9	Oct. 10	Nov. 11	Dec. 12
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29	60	88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

[1/] For leap year, add 1 day to totals for days Mar. through Dec.

line printer file, then obtains more hourly data. The program will continue to process data until an end of file statement appears on the input file.

Daily Tabulation of Data

After hourly data are processed as daily summaries, the daily precipitation values are keypunched on cards, and the output is listed (table 4).

Table 4--*Example of daily climatic data summary*[1/][2/]

ID	YR JD	SOL RAD	AVG DAY TEMP	MAX DAY TEMP	AVG NGT TEMP	MIN NGT TEMP	AVG DAY DP	MAX DAY DP	AVG NGT DP	MIN NGT DP	WIND MOVEMENT DAY	WIND MOVEMENT NGT	DAY HRS	PRECIP
M07D	75306	131.9	10.7	12.0	11.4	10.0	3.7	6.0	3.6	3.0	1.6	2.3	10	1.30
M07D	75307	77.9	14.9	18.0	6.1	3.0	8.0	10.0	5.3	3.0	2.9	5.8	10	0.00
M07D	75308	209.9	12.9	19.0	6.6	4.0	9.1	13.0	1.9	0.0	3.5	4.8	10	0.00
M07D	75309	180.0	7.7	9.0	3.5	3.0	5.4	9.0	2.1	1.0	8.4	4.5	10	.56
M07D	75310	65.9	4.0	5.0	3.9	1.0	4.0	5.0	4.0	1.0	5.2	5.8	10	4.09
M07D	75311	30.0	4.9	6.0	1.9	1.0	4.9	6.0	1.9	1.0	2.9	3.2	10	1.72
M07D	75312	65.9	2.3	3.0	1.0	1.0	2.3	3.0	1.0	1.0	6.4	1.6	10	.96
M07D	75313	77.9	2.8	4.0	1.1	0.0	2.8	4.0	1.1	0.0	2.3	10.9	10	.56
M07D	75314	83.9	1.8	4.0	.9	0.0	1.8	4.0	.9	0.0	6.4	1.6	10	2.87
M07D	75315	71.9	3.3	5.0	-.6	-3.0	-1.5	0.0	-3.0	-3.0	3.9	7.1	10	.36
M07D	75316	173.9	2.4	7.0	-.9	-3.0	.8	3.0	-3.4	-6.0	4.5	6.8	10	
M07D	75317	155.9	3.6	10.0	2.1	0.0	-.6	4.0	-4.0	-5.0	3.5	6.8	10	
M07D	75318	119.9	6.5	8.0	7.2	6.0	6.5	8.0	7.2	6.0	2.9	8.1	10	2.82
M07D	75319	59.9	5.6	6.0	2.5	2.0	5.6	6.0	2.5	2.0	5.2	2.9	9	3.48
M07D	75320	47.9	2.9	4.0	.3	0.0	2.9	4.0	.3	0.0	10.3	8.7	9	1.32
M07D	75321	60.0	1.6	3.0	-1.9	-3.0	1.6	3.0	-1.9	-3.0	1.9	5.5	9	.74
M07D	75322	89.9	2.1	6.0	-3.7	-5.0	-1.7	-1.0	-5.2	-6.0	4.5	7.4	9	0.00
M07D	75323	131.9	.6	6.0	-.5	-1.0	-2.0	1.0	-1.2	-2.0	4.5	6.1	9	0.00
M07D	75324	65.9	2.7	5.0	.2	-2.0	-1.9	0.0	-3.6	-4.0	1.3	5.2	9	.33
M07D	75325	53.9	3.0	9.0	-.8	-3.0	-1.0	0.0	-3.6	-5.0	4.2	6.4	9	.05
M07D	75326	107.9	2.6	5.0	2.6	2.0	2.6	4.0	2.6	2.0	2.3	3.5	9	1.40
M07D	75327	59.9	6.3	10.0	1.4	-1.0	-1.0	1.0	-.7	-1.0	1.9	5.2	9	.03
M07D	75328	77.9	3.9	6.0	5.0	5.0	2.6	6.0	-2.2	-4.0	2.6	2.3	9	.20
M07D	75329	36.0	6.0	7.0	5.4	5.0	1.1	2.0	3.5	1.0	99.0	99.0	9	.10
M07D	75330	83.9	5.4	6.0	3.3	2.0	5.4	6.0	2.2	2.0	99.0	99.0	9	4.62
M07D	75331	47.9	3.4	4.0	0.0	-1.0	2.6	4.0	-.3	-1.0	99.0	99.0	9	.86

[1/] ID is the data set identification code; YR JD are the last two digits of the year followed by the Julian day number; solar radiation is in units of calories per square centimeter per day; temperatures are in degree Celsius; DP is dewpoint; wind movement is in kilometers; DAY HRS is day length in hours; precipitation is in centimeters; 99.0 indicates missing data as listed on the last 4 days under wind movement.

[2/] Complete data sets are available from Richard H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon 97331, for $1.50 per year, upon request.

Editing of Data

Averages and totals for each day are essential when daily water, energy, and mineral transfer through forest ecosystems are estimated. To meet these requirements, the senior author edited the original daily summaries and flagged missing or suspicious data. In the editing procedures, radiation on apparently clear days without recorded precipitation was compared with previously compiled observed values (fig. 6). Radiation values more than 10 percent above or below the predicted values led to closer inspection of the preceding 30 to 50 days of data. Sometimes the radiometer output progressively decreased, probably the result of water shorting out the sensor. In such cases, a systematic reduction below the expected values (fig. 6) resulted in a correction applied to compensate for the decrease. Usually such corrections were less than 10 percent of the observed radiation in any given month.

In 1975 a more rugged radiometer with a lower output signal was installed, and a constant 75 langleys per day had to be added on clear days to correct for radiation below recordable levels at dawn and dusk periods. At other times when the radiometer became inoperative, correlations with temperature and precipitation patterns in the same month in previous years were used to estimate the missing values. Such periods are identified in table 2.

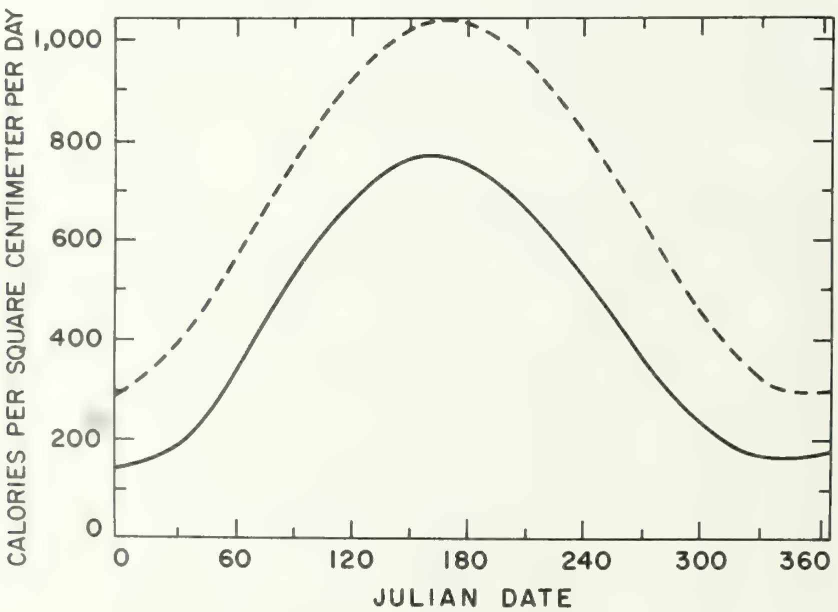


Figure 6.--Yearly variation in potential short-wave radiation reaching the earth's atmosphere (dotted line) and the maximum radiation reaching the earth's surface at 45°N. latitude (solid line).

Dewpoint was most difficult to
sure accurately and continuously;
shown by the large amount of
sing data (table 2). The impor-
ce of dewpoint data increases as
poration and radiation increase,
fortunately, this corresponds
h the dry season when instrument
ration normally is satisfactory.

Only rarely did the air tempera-
e recorder fail to operate. In
se instances, a nearby thermo-
ph provided data that agreed
hin 1°C. Periods when missing
a were supplied from this source
also identified in table 2.

On the hourly summaries prepared
ore keypunching, the senior author
sured that dewpoint temperatures
er exceeded air temperatures.
ause chart readings may err by
, rainy days occasionally had
point values listed a degree or
above air temperature. When that
ppened, they were made to equal
r temperature.

Fortunately, failure of the
point sensor generally occurs
ing cold wet weather when the
r is nearly saturated with water
por and the dewpoint and air
nperatures are nearly equal any-
y. The importance of this fact
n be illustrated by comparing the
aporative demand in winter with
aporative demand in summer. To
cilitate comparison, figure 7 il-
strates the relationship between
mperature and the water-holding
pacity of air. To calculate the
erage evaporative demand, first
termine the average day temperature
d then read from the graph the
rresponding vapor pressure:
0 mmHg = 1 013 mbar. The dif-
rence in vapor pressure at air
mperature and at dewpoint indicates
e evaporative demand.

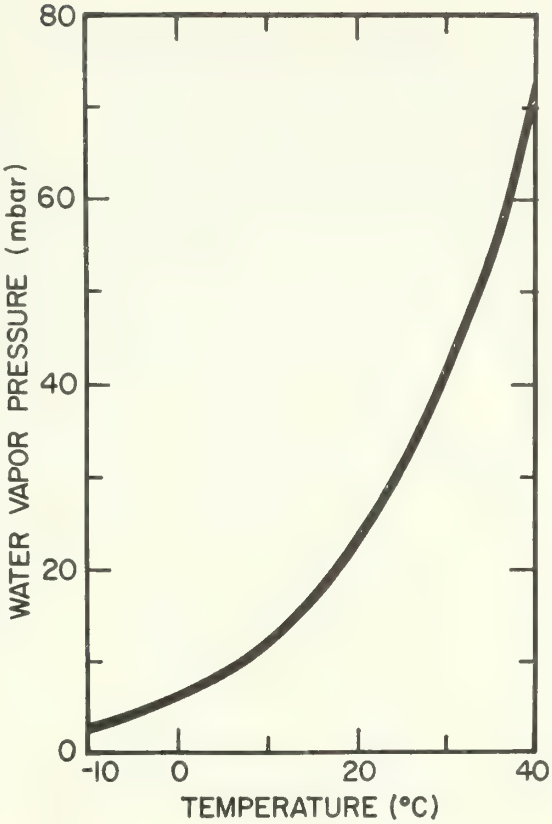


Figure 7.--Saturated vapor pressure (mbar) of water in relation to air temperature where vapor pressure = $6.1078 \exp\left(\frac{17.269T}{237 + T}\right)$.

On an unusual winter day (March 75073), the air temperature averaged 12°C and the dewpoint -1.5°C. Figure 7 shows that, if saturated, the water vapor concentration of air at 12°C would be 12.3 mbar. The amount actually in the air is equivalent to the saturation value at the dewpoint temperature, or only 5.5 mbar. The evaporative demand under these rather rare winter conditions is 6.8 mbar. Usually the demand in winter averages less than 2 mbar.

To fill in missing dewpoint temperature data during the dry season, we tried to define correlations between the night temperatures,

which cooled the air and presumably condensed water vapor, and daytime dewpoint temperatures which might reflect the extent of cooling the previous night. Selecting days from April through September that were not preceded by rainfall for at least 5 days, we found general agreement between the average night temperature and the average-day dewpoint temperature (fig. 8). This relationship did not hold during extremely hot days in August when the night temperature did not approach dewpoint. Fortunately, the instrument did not fail in these periods. Most of the missing dewpoint data were estimated by assuming that average night temperature corresponds to average-day dewpoint temperature, unless precipitation occurs. Under the latter condition, more than 0.5 cm of precipitation was assumed to correspond to a saturated atmosphere, and dewpoint temperature was assumed to correspond with air temperature. With less precipitation, dewpoint temperature was estimated at an intermediate value above the average night temperature and below the average-day temperature.

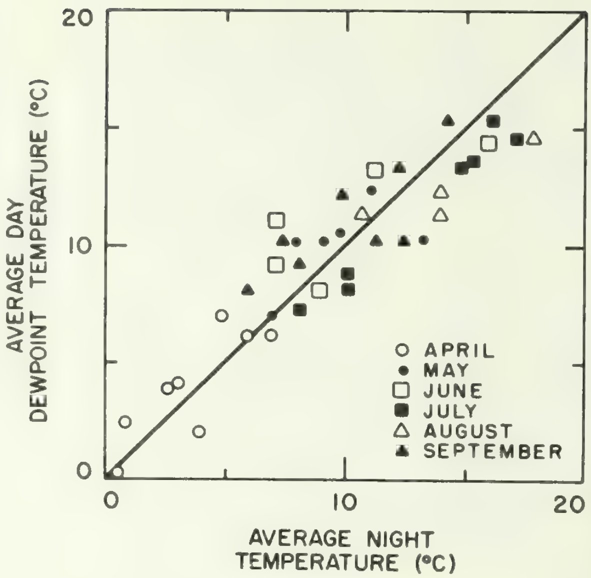


Figure 8.--Relationship between average night temperature and average daily dewpoint temperature. Data were selected for days that followed a 5-day period without precipitation.

English Equivalents

1 hectare = 2.47 acres
1 meter = 3.27 feet
1 kilometer = 0.625 mile

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Appendix

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      PROGRAM M070PRG(TAPE3,TAPE4,TAPE6,OUTPUT,TAPE61=OUTPUT)
C
C**********************************************************************
C****************** PROGRAMMER - RAY BUEB ****************************
C****************** DATE 5/25/75  CDC CYBER  KRONOS 2.1  FORTRAN EXT. 4.3
C****************** REVISED 8/1/75 ***********************************
C**********************************************************************
C
C**********************************************************************
C****************** DESCRIPTION ***************************************
C**********************************************************************
C
C        PROGRAM TO CONVERT BCD CARD IMAGE M07H(HOURLY) DATA TO BCD CARD IMAGE
C        M07D(DAILY) DATA.  READ 6 CARDS WITH 4 HRS. DATA ON EACH CARD.
C        YOUR HOURLY INPUT DATA MUST CONTAIN SIX CARDS FOR EACH JULIAN DAY.
C        EACH CARD CONTAINS SOLAR RADIATION, AIR TEMPERATURE, DEW POINT
C        TEMPERATURE, AND WIND MOVEMENT, FOR EACH HOUR IN THE FOLLOWING
C        FORMAT:
C
C     CARD      HOURS
C
C       1         1-4
C       2         5-8
C       3         9-12
C       4        13-16
C       5        17-20
C       6        21-24
C
C  COLUMN     VARIABLE                                                 FORMAT
C
C  1- 4        IDENTIFIER OF DATASET                                   A4
C  5- 6        SEQUENCE NUMBER PERTAINING TO CARD POSITION (1-6)       I2
C  7- 9        YEAR OF DATA COLLECTION                                 I3
C 10-13        JULIAN DAY                                              I4
C 14-16        SOLAR RADIATION    * HOURS                              F3.1
C 17-20        AIR TEMPERATURE    * 1,5,9,13,17,21                     F4.0
C 21-24        DEW PT TEMPERATURE *                                    F4.0
C 25-29        WIND MOVEMENT      *                                    F5.0
C 30-32        SOLAR RADIATION        * HOURS                          F3.1
C 33-36        AIR TEMPERATURE        * 2,6,10,14,18,22                F4.0
C 37-40        DEW PT TEMPERATURE     *                                F4.0
C 41-45        WIND MOVEMENT          *                                F5.0
C 46-48        SOLAR RADIATION             * HOURS                     F3.1
C 49-52        AIR TEMPERATURE             * 3,7,11,15,19,23           F4.0
C 53-56        DEW PT TEMPERATURE          *                           F4.0
C 57-61        WIND MOVEMENT               *                           F5.0
C 62-64        SOLAR RADIATION                  * HOURS                F3.1
C 65-68        AIR TEMPERATURE                  * 4,8,12,16,20,24      F4.0
C 69-72        DEW PT TEMPERATURE               *                      F4.0
C 73-77        WIND MOVEMENT                    *                      F5.0
C
C
C********************************************************************
C****************** INPUT, OUTPUT UNITS *****************************
C********************************************************************
C
C        TAPE3= M07H. MUST HAVE 6 CARDS FOR EVERY JULIAN DAY (ERRORS WIL
C               DETECTED BY PROGRAM). IF YOU HAVE A COMPLETE YEARS DATA
C               MUST HAVE THE FIRST DAY OF THE NEXT YEAR AFTER THE LAST
C               ORDER TO GET DAILY AVERAGES FOR THE LAST DAY.
C        TAPE4= LINE PRINTER OUTPUT OF DAILY AVERAGES
C        TAPE6= CARD IMAGE M07D DATA (DAILY AVERAGES) TO BE PUNCHED
C        TAPE61= ERROR MESSAGES
```

```
C
C***********************************************************************
C****************** VARIABLES ******************************************
C***********************************************************************
C
C     A        IDENTIFIER FOR DATA SET M07D (DAILY AVERAGES OF M07H)
C     AT       AIR TEMPERATURE FROM TAPE3
C     DAY      ARRAY CONTAINING SUNRISE (OF CURRENT JD), DAYLENGTH (OF CU
C              CURRENT JD),SUNSET (OF CURRENT JD), AND SUNRISE (OF NEXT JD)
C     DP       DEW POINT FROM TAPE3
C     ICOUNT   NUMBER OF LINES OF PRINT PER PAGE
C     XID      COUNTER FOR NUMBER OF RECORDINGS OF SOLAR RADIATION
C     IDAY     INTEGER COUNTERPART OF VARIABLE DAY
C     IERRC    COUNTER OF ERRORS FOR TAPE3 IF NOT 6 CARDS PER DAY
C     ILOOP    TOTAL DAY LENGTH FOR DAILY AVERAGED DAY
C     IY       DAILY AVERAGED SOLAR RADIATION
C     IQ,IE    COUNTERS USED TO READ IN HOURLY DATA
C     ISEQ     SEQUENCE CHECK FOR 6 CARDS PER DAY
C     IYEAR    YEAR
C     JULCK    DAY SEQUENCING CHECK VARIABLE
C     JULDAY1  JULIAN DAY INDICATORS USED TO CHECK FOR MORE OR LESS THAN
C     JULDAY2     6 CARDS READ IN ON INPUT FILE TAPE3
C     JD       JULIAN DAY FROM INPUT FILE TAPE3
C     NA       COUNTER USED TO REORDER INPUT DATA INTO DAY AND NIGHT
C     NLGTH    NIGHT LENGTH FOR DAILY AVERAGED DAY
C     SOLAR    ERROR CHARACTER (/) FOR SOLAR RADIATION < 50 AND > 990
C     SR       SOLAR RADIATION FROM TAPE3
C     SSR      SUM OF SOLAR RADIATION
C     SWSD     SUM OF WIND MOVEMENT DURING THE DAY
C     SWSN     SUM OF WIND MOVEMENT DURING THE NIGHT
C     SNAT     SUM OF NIGHTIME AIR TEMP + AVG. NGT TEMP
C     SNDP     SUM OF NIGHTIME DEW POINT TEMP + AVG. NGT DEW TEMP
C     SDAT     SUM OF DAYTIME AIR TEMP + AVG. DAY TEMP
C     SDDP     SUM OF DAYTIME DEW POINT TEMP + AVG. DAY DEW TEMP
C     WS       WIND MOVEMENT FROM TAPE3
C     XDAT     MAX DAYTIME AIR TEMP
C     XDDP     MAX DAYTIME DEW POINT TEMP
C     XNAT     MIN NIGHTIME AIR TEMP
C     XNDP     MIN NIGHTIME DEW POINT TEMP
C     XAT      STORAGE ARRAY FOR AIR TEMPERATURE DIVIDED INTO NIGHT AND DAY
C     XDP      STORAGE ARRAY FOR DEW POINT TEMP  DIVIDED INTO NIGHT AND DAY
C     XSR      STORAGE ARRAY FOR SOLAR RADIATION DIVIDED INTO NIGHT AND DAY
C     XWS      STORAGE ARRAY FOR WIND MOVEMENT   DIVIDED INTO NIGHT AND DAY
C     Z        REAL FORMAT OF IY
C
      DIMENSION SR(2,24),AT(2,24),DP(2,24),WS(2,24),JD(2),DAY(4),IDAY(4)
     1  ,XSR(30),XAT(30),XWS(30),XDP(30)
      DATA (SOLAR=10H       /   )
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C         CHECK FOR 6 CARDS PER DAY IN ASCENDING SEQUENCING ORDER 1-6
C          AND THAT DAYS ARE CONSECUTIVE. CHECK FOR EACH HOUR, AIR TEMP >
C          DEW TEMP.
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      READ(3,201) ISEQ,IYEAR,JULCK
      BACKSPACE 3
      JULCK=JULCK-1
      IERRC=0
  205 DO 200 J=1,6
      IF(J.NE.1) GO TO 202
      READ(3,201) ISEQ,IYEAR,JULDAY1,(XAT(N),XDP(N),N=1,4)
  201 FORMAT(4X,I2,I3,1X,I3,4(3X,2F4.0,5X))
      IF(EOF(3)) 250,209
  202 READ(3,201) ISEQ,IYEAR,JULDAY2,(XAT(N),XDP(N),N=1,4)
```

```
      IF(EOF(3)) 240,203
  240 WRITE(61,241)
  241 FORMAT(≠ CAN NOT HAVE LESS THAN 6 CARDS ON LAST DAY≠)
      STOP ≠PROBLEM WITH INPUT≠
  203 CALL ERRCK(XAT,XDP,IERRC,IYEAR,JULDAY2,ISEQ)
      IF(ISEQ.NE.J) WRITE(61,210) IYEAR,JULDAY1
      IF(ISEQ.NE.J) IERRC=IERRC+1
      IF(JULDAY1.EQ.JULDAY2) GO TO 200
      WRITE(61,204) IYEAR,JULDAY1,JULDAY2
  204 FORMAT(≠ PROBLEM ON INPUT FILE TAPE3 BETWEEN YEAR≠,I3,≠ JULIAN
     *DAYS≠,I4,≠ AND≠,I4)
      GO TO 206
  209 CALL ERRCK(XAT,XDP,IERRC,IYEAR,JULDAY1,ISEQ)
      IF(JULDAY1.EQ.366) GO TO 211
      IF(JULCK.GE.365) JULCK=0
  211 IF((JULCK+1).EQ.JULDAY1) GO TO 213
      WRITE(61,212) IYEAR,JULCK,JULDAY1
  212 FORMAT(≠ DAY MISSING BETWEEN YEAR≠,I3,≠ JULIAN DAYS≠,I4,≠ AND≠,I4)
      IERRC=IERRC+1
  213 IF(ISEQ.EQ.J) GO TO 200
      WRITE(61,210) IYEAR,JULDAY1
  210 FORMAT(≠ CARDS OUT OF SEQUENCE YEAR≠,I3,≠ JULIAN DAY ≠,I3)
      IERRC=IERRC+1
  200 CONTINUE
      JULCK=JULDAY1
      GO TO 205
  206 IERRC=IERRC+1
      BACKSPACE 3
      JULCK=JULDAY1
      GO TO 205
  250 IF(IERRC.NE.0) STOP ≠PROBLEM WITH INPUT≠
      REWIND 3
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C         SET INITIAL INDICATORS + ARRAYS
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      ICOUNT=28
      A=4HM070
    1 XID=0.
      ERRORS=10H
      XDAT=XDDP=XNAT=XNDP=SWSD=SSR=SNAT=SNDP=SDAT=SDDP=SWSN=0
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C         READ IN CURRENT DAY AND FOLLOWING DAY
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      DO 155 IOI=1,2
      IQ=1
      IE=4
      DO 15 M=1,6
      READ (3,10)  IYEAR,JD(IOI),(SR(IOI,I),AT(IOI,I),DP(IOI,I),WS(IOI,I
     1 ),I=IQ,IE)
   10 FORMAT (6X,I3,X,I3,4(F3.1,2F4.0,F5.0))
      IF (EOF(3)) 30,31
   31 IQ=IQ+4
   15 IE=IE+4
  155 CONTINUE
      DO 989 J=1,6
  989 BACKSPACE 3
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C         CALCULATE SUNRISE, DAYLENGTH, AND SUNSET OF CURRENT JD AN
C            SUNRISE OF THE NEXT JD
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      K = JD(1) - 86
      IF (K .LT. 0) K = K + 365
      DAY(1) = 6.06666 - 1.675*SIN(K*.017214)
```

```
      K = K + JD(2) - JD(1)
      DAY(4) = 6.06666 - 1.675*SIN(K*.017214)
      K = JD(1) - 81
      IF (K .LT. 0) K = K + 365
      DAY(2) = 12.23333 + 3.35*SIN(K*.017214)
      DO 6 K = 1,4
      IF(K.EQ.3) GO TO 6
      IDAY(K)=IFIX(DAY(K))
      X=(DAY(K)-FLOAT(IDAY(K)))*60.
      IF (X .GE. 30.) IDAY(K) = IDAY(K) + 1
      IF (K.NE.2) IDAY(K)=IDAY(K)+1
    6 CONTINUE
C**** ONE DAY IS ADDED TO SUNRISE CALCULATIONS BECAUSE OF
C**** METHOD OF DATA COLLECTION.
      IDAY(3) = IDAY(1) + IDAY(2)
      NLGTH=24-IDAY(3)+IDAY(4)
      ILOOP=NLGTH+IDAY(2)
      NA=IDAY(1)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C        PUT INPUT DATA INTO DAY AND NIGHT OF CURRENT JULIAN DAY
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      DO 818 J=1,30
  818 XAT(J)=XDP(J)=XWS(J)=XSR(J)=0
      DO 919 J=1,1000
      XAT(J)=AT(1,NA)
      XDP(J)=DP(1,NA)
      XSR(J)=SR(1,NA)
      XWS(J)=WS(1,NA)
      IF(NA.EQ.24) GO TO 918
  919 NA=NA+1
  918 K=IDAY(4)-1
      DO 917 NA=1,K
      J=J+1
      XAT(J)=AT(2,NA)
      XSR(J)=SR(2,NA)
      XWS(J)=WS(2,NA)
  917 XDP(J)=DP(2,NA)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C        PROCESS 24 HOURS OF XSR, XAT, XDP, XWS TO GET DAILY AVERAGES
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      DO 3 J=1,ILOOP
      IF(J.LE.IDAY(2)) GO TO 4
C
C             NIGHTIME
C
      SWSN=SWSN+XWS(J)
      SNAT=SNAT+XAT(J)
      SNDP=SNDP+XDP(J)
      IF(J.GT.IDAY(2)+1) GO TO 5
      XNAT=XAT(J)
      XNDP=XDP(J)
      GO TO 3
    5 IF (XAT(J) .GE. XNAT) GO TO 8
      XNAT=XAT(J)
    8 IF (XDP(J) .GE. XNDP)  GO TO 3
      XNDP=XDP(J)
      GO TO 3
C
C             DAYTIME
C
    4 SWSD=SWSD+XWS(J)
      IF(XSR(J).LE.0) GO TO 60
      XID=XID+1.
```

```
      SSR=SSR+XSR(J)
      SSR=SSR+XSR(J)
   60 SDAT=SDAT+XAT(J)
      SDDP=SDDP+XDP(J)
      IF(J.GT.1) GO TO 11
      XDAT=XAT(J)
      XDDP=XDP(J)
      GO TO 3
   11 IF (XAT(J) .LE. XDAT) GO TO 13
      XDAT=XAT(J)
   13 IF (XDP(J) .LE. XDDP) GO TO 3
      XDDP=XDP(J)
    3 CONTINUE
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C         MAKE NEW DATA FILE M07D
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
       IF(XID.GT.0.) GO TO 75
      IY=0
      SSR=0.
      GO TO 76
   75 SSR=(SSR/XID)*(XID*60.)
      IY=IFIX(SSR*10.+.05)
   76 IF(SSR.LE.990.) GO TO 77
      SSR=990.
      IY=9900
   77 SWSD=.322*SWSD
      SWSN=.322*SWSN
      IF(SWSD.GE.99.) SWSD=99.
      IF(SWSN.GE.99.) SWSN=99.
      SDAT=SDAT/IDAY(2)
      SDDP=SDDP/IDAY(2)
      SNAT=SNAT/NLGTH
      SNDP=SNDP/NLGTH
C             CHECK ERRORS FOR RADIATION
      IF(SSR.GE.800..OR.SSR.LE.50.) ERRCRS=ERRORS.AND.SOLAR
      WRITE(6,70) A,IYEAR,JD(1),IY,SDAT,XDAT,SNAT,XNAT,SDDP,XDDP,SNDP,XN
     *DP,SWSD,SWSN,IDAY(2)
   70 FORMAT(A4,2I3,I5,10F5.1,I3)
C           IS HEADING NECESSARY
      IF (ICOUNT.LE.27) GO TO 80
      WRITE (4,20)
   20 FORMAT(≠1≠,//,17X,2(2X,≠AVG   MAX   AVG   MIN≠),6X,≠WIND≠,/,14X,
     *≠SOL≠,2(2X,≠DAY   DAY   NGT   NGT≠),≠   MOVEMENT DAY≠,/,
     *≠    ID YR JD   RAD≠,4(≠ TEMP≠),4(≠    DP≠),≠  DAY   NGT HRS≠)
      ICOUNT=0
   80 WRITE (4,16) A,IYEAR,JD(1),SSP,SDAT,XDAT,SNAT,XNAT,SDDP,XDDP,SNDP,
     1XNDP,SWSD,SWSN,IDAY(2),ERRORS
   16 FORMAT(≠0≠,A4,2I3,F6.1,10F5.1,I3,A10)
      ICOUNT=ICOUNT+1
      GO TO 1
   30 STOP ≠END OF RUN≠
      END
      SUBROUTINE ERRCK(XAT,XDP,IERRC,IYEAR,JULDAY,ISEQ)
C
C  CHECK TO SEE IF AIR TEMP, (XAT) IS > DEW TEMP (XDP) FOR
C  HOURS PASSED.
C
      DIMENSION XAT(30),XDP(30)
      DO 1 J=1,4
      IF(XAT(J).GE.XDP(J)) GO TO 1
      IERRC=IERRC+1
      IHOUR=(ISEQ-1)*4+J
      WRITE(61,2) IYEAR,JULDAY,IHOUR
```

```
 2 FORMAT(≠ FOR YEAR≠,I3,≠ JULIAN DAY≠,I4,≠ HOUR≠,I3,≠ AIR TEMP≠,
  1≠ < DEW TEMP≠)
 1 CONTINUE
   RETURN
   END
```

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Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
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P.O. Box 3141
Portland, Oregon 97208

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PROCEEDINGS of the WESTERN JUNIPER ECOLOGY AND MANAGEMENT WORKSHOP

BEND, OREGON

JANUARY 1977

PACIFIC NORTHWEST FOREST and RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT of AGRICULTURE
PORTLAND, OREGON

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INTRODUCTION

Western juniper (*Juniperus occidentalis* subsp. *occidentalis*) is an important invader of range lands in central and eastern Oregon. Many people have asked questions about its control, effect on range productivity, and its benefits. The papers in this proceedings resulted from a conference held in Bend, Oregon, January 1977, to summarize our knowledge of western juniper and to evaluate research needs.

THE SPREAD OF WESTERN JUNIPER IN CENTRAL OREGON

David L. Caraher, District Ranger
Crooked River National Grassland
United States Forest Service
Prineville, Oregon

ABSTRACT

The probability that western juniper is increasing at a phenomenal rate throughout its range is shown, drawing upon written record, photographic record, and casual observation. Scarcity of knowledge about this plant leaves land managers to make uninformed decisions about its management. Meanwhile, a much needed research campaign to answer principal questions about western juniper has yet to be organized.

Keywords: Western juniper, invasion, range, Oregon

OCCURRENCE AND DISTRIBUTION

Western juniper (*Juniperus occidentalis* Hook.) is principally a native to central Oregon, with some distribution extending east into Idaho, north into southeastern Washington, and south into California and Nevada. It lives nowhere else.

Stand Characteristics: Cause for Concern

Where they grow, stands of western juniper are generally accepted as a characteristic part of the landscape. They appear to be well established and form a logical transition between the open plains and the pine timber. They look like they belong. A closer look raises some doubts.

First of all, many dense stands of western juniper, ones that appear to be a forest, conspicuously lack dead standing trees and logs. Furthermore, there are often no big older trees, so common to other forests, and no scattering of seedlings or saplings in the understory. Instead, these western juniper forests appear as a collection of uniform trees. These facts lead us to two important speculations: one, these stands are relatively young; and two, the trees within them originated at about the same time.

Through increment boring, that is removing a core sample of the trunk's growth rings, we can often confirm both speculations for a given stand. The year of germination varies, but mostly falls between 1870 and 1910.

Supporting Evidence

Written Records. In 1870, land surveyors under contract to the federal government came to central Oregon to set township and section corners as a necessary prerequisite to homesteading. Part of their task was to observe and record information about soils and vegetation. As it turns out, they were the first to make such a systematic survey here. We still have their notes, which unfortunately are sketchy in soils and vegetation data. Nonetheless, they are descriptive, and they are also official, which lends credence to the descriptions.

On October 15, 1870, having finished a survey of Township 13 South, Range 13, East of the Willamette Meridian, deputy surveyor John W. Meldrum wrote the following summary description:

> "The land in this township is gently rolling except in the southwestern part which is hilly: soil generally good second rate. There is some juniper timber in the south western part, but quite scattering. Good bunchgrass in abundance grows all over the township......"

That is a very sketchy record, but it is also very specific about location. Since we still use this original survey for land location, we can easily find the place just described. Instead of juniper being "quite scattering", we find the junipers form a veritable forest with 80 to 100 trees per acre.

Photographic Record. Long-time residents of central Oregon confirm that the juniper dominance we now see has come about during their lifetime. Occasionally they have the pictures to prove it.

In 1888, pioneer Richard Breese made his homestead in Gravy Gulch, just south of Prineville in central Oregon. His original cabin is still standing, and now looks like so many other shacks around the countryside. However, unlike so many others, this one was photographed when it was still new, and when, in sharp contrast to Gravy Gulch now, there were no junipers. A second photograph taken in 1976 documents the contrast.

A 1915 photograph of the town of Ashwood (just north of central Oregon) shows just a few junipers dotting the hills in the background. A second photo, taken of the same hills in 1968, shows the kind of heavy juniper cover that we have come to accept as natural.

Other old photographs, taken in other parts of western juniper's geographic distribution from Dayville in eastern Oregon to the Lava Beds National Monument just below the southern Oregon border, show the same phenomenon. It appears that in the last 100 years, western juniper has been increasing at an alarming rate.

IMPLICATIONS OF THE INCREASE

The cause for alarm comes from two sources. First, we suspect that the juniper requires enormous amounts of water and can out-compete all other plants surrounding it. If this is true, thousands of acres of rangeland and watershed will be affected.

The second cause for alarm is that a mature juniper tree is a formidable plant. Traditional plant control methods of chemical or mechanical means are proving to be too expensive or ineffective.

Management Questions

The prospect of a formidable plant drastically reducing the productivity of thousands of acres of rangeland quickly raises four questions:

1. Is western juniper really invading rangeland?
2. If there is an invasion, is that bad?
3. What's causing it?
4. What can we do about it?

Is western juniper really invading rangeland? Old survey notes and old photographs can present convincing evidence, but not the definitive, quantitative kind of support on which to launch a major research or control program. We need to be far more specific. Within this major question, there are a series of sub-questions.

- How many acres did western juniper occupy before 1900 and where were they?
- How many acres does it occupy now and where are they?
- What, if any, is the percent of increase?
- Left unchecked, what is the forecast of acres to be occupied 10 years from now?

If there is an invasion, is it bad? Land managers, especially range managers have learned that plant invasions in general are bad. Plants that increase their cover, range or density at a phenomenal rate are weeds. They have no value and they live at the expense or detriment of plants that do have value. What about juniper?

We suspect, that left unchecked, in 50 years western juniper will dominate most of the rangelands where it now grows. Will soil erosion be increased from these sites by the tons per year? Will forage plants be gone, having been unable to compete with juniper for water? Will lower elevation rangeland, even if not occupied by juniper, suffer from lack of soil moisture, because upland juniper is using what used to come down as sub-surface flow?

On the other hand, it is possible that as a result of some silvicultural and wood technology advancements, western juniper wood will become a commodity. With this possibility, harvest may or may not keep up with the rate of juniper increase. We may learn that wildlife variety and numbers increase as junipers increase.

The possibilities are endless. The point is, we don't know what to expect because juniper's effect on soil moisture, plant competition, or wildlife have not been identified. We can't launch a major control effort by assuming juniper is bad; we're going to have to find out what effect it has on other components of the ecosystem.

What is causing the invasion? We ask this question usually because we assume that the key to curing a problem lies with its cause. Unfortunately with juniper there is a long term time lag involved. The chances are that once we find the cause, it will help 20 years from now, and not tomorrow. But we still must be interested in cause, because it will probably be our cheapest solution in the long run. Without trying to answer the question here, I will just point out that as land managers we have reason to suspect

- birds are involved--they transport the seed to new locations
- fire is involved, we know it kills juniper; without fire, there seems to be no natural check on juniper
- sagebrush may be involved; many new juniper are born under a sagebrush where they were planted by birds
- grazing may affect the rate of juniper invasion

What can be done about juniper invasion? Just asking this question assumes that there is at least some level of juniper invasion going on, and that some of it is bad. If those assumptions prove true, then land managers will need to know more about juniper control methods than they do now. We need to know what works, what works best in what circumstances, and what are the costs and impacts of different control methods.

CONCLUSION

We suspect that western juniper is increasing at an alarming rate. We also suspect that this increase will ultimately destroy thousands

of acres of range. Currently, land managers have to base these suspicions on educated guesses, personal observations and experience. There is very little information available on the management of western juniper. Management decisions are based on the same weak footing as are suspicions.

We don't know much about western juniper and we need to know a great deal. However, that is only half of the problem. The other half is that as of the date of this paper, there is no known effort to find the needed answers; meanwhile, western juniper is still growing.

SECTION I

BIOLOGY

COMMUNITIES OF WESTERN JUNIPER IN THE INTERMOUNTAIN NORTHWEST

J. Edward Dealy, Research Plant Ecologist
Pacific Northwest Forest and Range Experiment Station
La Grande, Oregon

J. Michael Geist, Research Soil Scientist
Pacific Northwest Forest and Range Experiment Station
La Grande, Oregon

Richard S. Driscoll, Principal Range Scientist
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

ABSTRACT

This paper presents a broad picture of western juniper (*Juniperus occidentalis* var. *occidentalis*) communities primarily from literature with some recent work by the authors. Vegetation-soil-site information is summarized from studies and surveys of central and southeast Oregon, northeast California, and southwest Idaho. Western juniper occurs on soils derived from a broad variety of parent materials--igneous, sedimentary, and metamorphic in origin. It occurs most commonly in association with big sagebrush (*Artemisia tridentata*), bluebunch wheatgrass (*Agropyron spicatum*), and/or Idaho fescue (*Festuca idahoensis*). Effective soil moisture and fire cycles are probably the main factors determining presence or absence of juniper under natural conditions. Since advent of efficient fire control measures and with overuse of rangelands by livestock during the same period, it appears that juniper has significantly increased its distribution and density in the zone. The entire mountain big sagebrush (*A. tridentata* subspp. *vasseyana*) type may be suitable for juniper expansion although lack of seed source has probably prevented it in the past.

Keywords: *Juniperus occidentalis* var. *occidentalis*, plant communities, vegetation-soil relationships.

INTRODUCTION

Western juniper (Juniperus occidentalis var. occidentalis) occurrence in the Intermountain Northwest is considered the northwest extension or representative of the pinyon-juniper woodland of the Intermountain Region (Cronquist et al. 1972, Driscoll 1964b, Billings 1952). The range of this variety of western juniper includes southeast Washington, southwest Idaho, eastern Oregon, northwest Nevada, and northeast California (Cronquist et al. 1972, Vasek 1966, and Little 1971) (Figure 1). The center of western juniper community development appears to be the large continuous woodland of central Oregon.

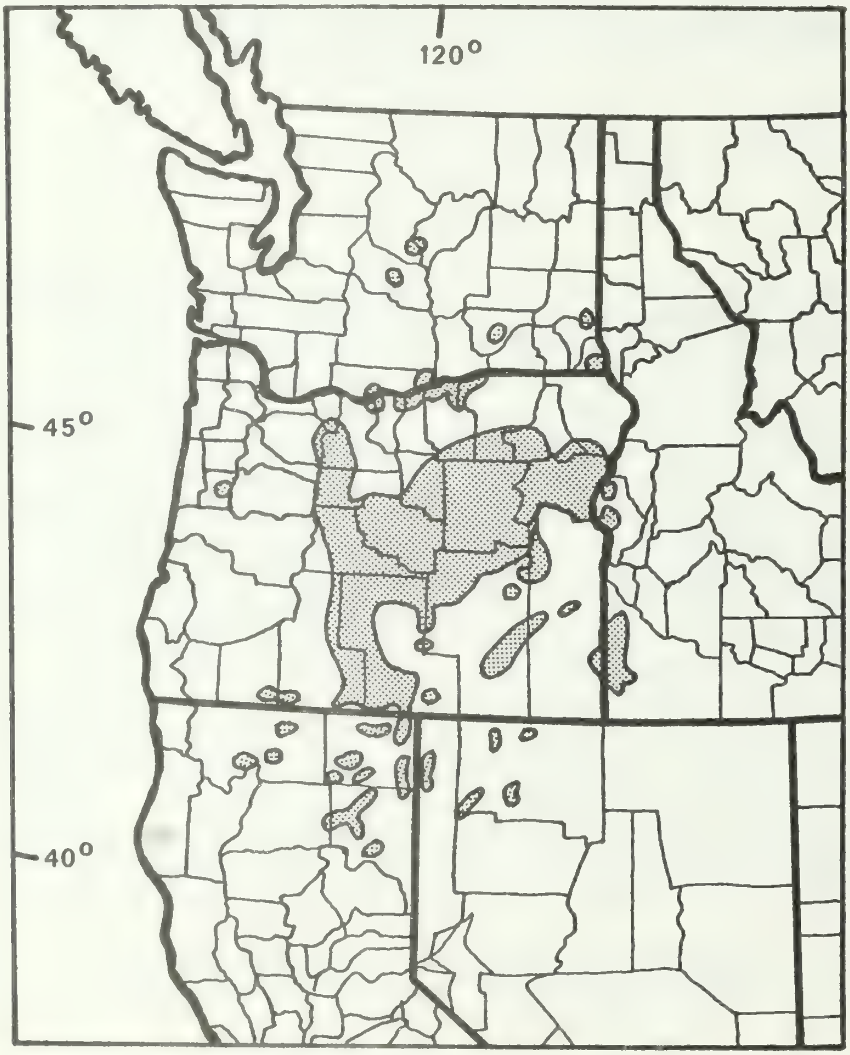

Figure 1.--Generalized distribution of western juniper (shaded portion). Tree densities vary among and within the different localities.

This paper presents a broad picture of these communities primarily from literature with some recent work by the authors. Vegetation-soil-site information will be discussed as well as some evaluation of western juniper in relation to interfacing high desert steppe communities such as big sagebrush (*Artemisia tridentata*) and curlleaf mountain-mahogany (*Cercocarpus ledifolius*).

WESTERN JUNIPER ZONE

The western juniper zone is spread across the Intermountain Northwest, being heavily concentrated and highly developed only in central and south-central areas of Oregon and to a lesser degree in northeastern California (Figure 1). The species occurs as single trees or small clumps throughout southeastern Oregon with a few stands in Harney and Malheur Counties developing significant woodland types. Burkhardt and Tisdale (1969) describe a study area in southwest Idaho as having approximately 161,878 hectares (400,000 acres) of juniper in various stages of succession or in climax stands.

The most intensive area of juniper study has been central Oregon where Driscoll (1964a, 1964b) analyzed nine associations including two variants, classifying them following polyclimax concepts. A large portion of the central Oregon juniper woodland zone in Driscoll's study area was so disturbed by overgrazing and farming, that it was unsuitable for analysis and placement in a hierarchy of successional and climax stages.

A standard soil survey was conducted by Leighty (1958) during the late 1940's and 1950's in this same area of disturbed communities. Leighty's vegetation notes indicated, of 1362 square kilometers (526 square miles) surveyed, over 99 percent had juniper occurring either as scattered trees or in more dense woodland situations.

To illustrate further extent of western juniper occurrence, we have compiled acreage data for soils supporting juniper in a north-south belt of central Oregon from Washington to the California border. These data are taken from a more recent compilation of soils information containing a supplemental generalized soil survey for purposes of reporting irrigable acreages in Oregon (Oregon Agric. Exp. Stn. and S.C.S. 1969). Although more general than a standard soil survey, the information provides an adequate guide to addressing occurrence of western juniper. This area is made up of the Deschutes River, Goose and Summer Lakes, and Klamath River drainage basins (Oregon Agric. Exp. Stn. and S.C.S. 1969). In the Deschutes River basin of 2,460,542 hectares (6,080,000 acres), juniper woodland occupied 8 percent of the area and scattered juniper occurred on 11 percent of the area. In the Goose and Summer Lake basins, juniper stands occurred on 14 percent of the 1,778,632 hectare (4,395,000 acres) area; no distinction was made between juniper woodland and scattered occurrence there. In the Klamath River basin of 1,410,360 hectares (3,485,000 acres), woodland stands occupied 15 percent of the area with scattered stands on another 15 percent.

We can present a general picture at best with these statistics since available plant data from our source was sketchy and land use of these areas changes continually. Further, we do not imply with these data that all areas are equally occupied in either "woodland" or "scattered tree" classes. However, these acreages are significant not only in size but also in terms of considering potential increased occupancy of these areas by western juniper.

Western juniper stands, though widely dispersed, constituted a very small percentage of area in southeastern Oregon. Eckert (1957) studied juniper dominated ecosystems over a large study area in this portion of the state.

Considerable information has been reported on western juniper communities of southwestern Idaho by Burkhardt and Tisdale (1969, 1976). They studied the nature and successional status of western juniper on the Owyhee Plateau and adjacent mountains in the west-central part of Owyhee County. The study effort was concentrated on two major vegetation communities--one considered climax and one seral.

Climate

Climate in this area is continental but modified somewhat by marine air from the Pacific Ocean. It is semiarid with typical intermountain characteristics of dry hot summers and cold winters with precipitation of 25 to over 51 cm (10 to over 20 inches) occurring principally as snow during winter and rain during spring and fall. Summer precipitation is generally sparse and ineffective. Frost can occur during any month in higher elevation areas; however, July and August are generally frost-free. Temperatures range from a low of $-47^{\circ}C$ ($-53^{\circ}F$) during January to a high of $46^{\circ}C$ ($114^{\circ}F$) during August (USDA 1941).

Soil and Site Characteristics

The following commentary represents a composite of soil-site data we found available for the western juniper zone and applies to essentially all occurrences of the species (Eckert 1957, Driscoll 1964b, Leighty 1958, Anderson 1956, Burkhardt and Tisdale 1976, Oregon Agric. Exp. Stn. and S.C.S. 1969, Franklin and Dyrness 1973).

Driscoll (1964b) recognized three physiographic subdivisions of this Northwest representative of the pinyon-juniper zone based on soil parent material. The first (his study area) was primarily eolian mixed igneous and pumice sands but included soils from coarser pumice, second was soils from igneous flows (mostly Miocene), and third was soils from Clarno and John Day sedimentary formations (Eocene and Oligocene epochs). At this time we see no reason to challenge this concept but have approached

he following discussion more generally.

Western juniper occurs on soils derived from a broad variety of parent materials--igneous, sedimentary, and metamorphic in origin. These include basalt, andesite, rhyolite, pumice, volcanic ash, tuff, welded tuff, and colluvial, alluvial or eolian mixtures of the preceeding. The mixtures may be rather homogeneous to highly stratified. As a result, western juniper is found on zonal, intrazonal, and azonal soils in a complex pattern over its present range of occurrence. Existing and potential stem density as well as growth and overall adaptability of western juniper vary over this spectrum.

Profile development differs among soils, but is often weak. Total depth ranges from deep (over 122 cm or 48 inches) to shallow (between 25 and 38 cm or 10-15 inches). They are commonly stony or gravelly and when shallow, broken indurated subsoil layers or fractured bedrock occur.

Textures vary from sandy to clayey. Surface horizons are usually medium textured with medium to fine textured subsoils. Hard pans or indurated layers occur in some cases and are associated with clay, calcium carbonate, and silica accumulations. These accumulations may be continuous or intermittent and vary in thickness from a thin band less than 1.5 cm (1/2 inch) to several centimeters. Surface soils are commonly dark brown when moist and gray brown to yellowish brown when dry.

Most soils supporting juniper have a mean annual soil temperature between 8^{o}-15^{o}C (48^{o}-59^{o}F), in the mesic temperature class; however, some are in the frigid class, $<8^{o}$ to $>5^{o}$C ($<48^{o}$ to $>41^{o}$F).

Western juniper occurs on essentially all exposures and slopes. The species is common on level to gently undulating topography of the High Lava Plains typified by the area between Redmond and Bend, Oregon. Moving away from this situation juniper occurs less continuously on moderately sloping alluvial fans, low terraces, canyon sideslopes, and steep escarpments. Elevational occurrence extends from 488 to 1982 meters (1600 to 6500 feet).

Very scattered juniper is found in fractured rockland areas on relatively flat topography resulting from geologically recent igneous flows. Occasional juniper plants are also found on steep rockland or talus slopes.

Soils mapped in the western juniper zone are primarily Brown, Regosol and Chestnut great soil groups within the old system of classification (Leighty 1958, Eckert 1957, Burkhardt and Tisdale 1969, Franklin and Dryness 1973). Within the latest soil taxonomic system, soils supporting juniper at higher densities are usually Mollisols; Argixerolls, Haploxerolls, and Haplaquolls are common great groups. Soils supporting scattered juniper are often Aridisols including Camborthids, Durargids, and Haplargids; however Argixerolls are also common. Sub-

stantial acreages of Durixerolls, Cryoborolls, Torriorthents, and Chromoxererts also support varied stands of juniper (Oregon Agric. Exp. Stn. and S.C.S. 1969).

Soil series common to the area include Agency, Deschutes, Madras, Merlin, Lorella, Tournquist, Lamonta, Metolius, Day, Maupin, Hack, Ayres, Courtrock, Fopiano, Ochoco, and Era.

Communities

Central Oregon. Western juniper is the primary conifer in the area and represents the driest tree-dominated zone in the Pacific Northwest. Occasional ponderosa pine (*Pinus ponderosa*) occurs in canyon bottoms, on north slopes or ridges extending out from the edge of the pine forest. Curlleaf mountain-mahogany interfaces with juniper at the edge of the high desert. Juniper is dominant in much of the area as an open woodland providing the aspect of a savanna (Figure 2). Big sagebrush is the dominant shrub understory in most communities; however, on some poor condition sites rabbitbrush (*Chrysothamnus* spp.) takes its place. On more moist sites big sagebrush is either replaced or shares the understory with antelope bitterbrush (*Purshia tridentata*). Other shrubs which occur in the area are low sagebrush (*Artemisia arbuscula*), horsebrush (*Tetrademia canescens*), granite gilia (*Leptodactylon pungens*), wax currant (*Ribes cereum*), spiny hopsage (*Grayia spinosa*), desert gooseberry (*Grossularia velutina*), and a suffrutescent erigonum (*Eriogonum* spp.). The grass layer varies between dominant stands of bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*) or mixes of these two. Other grasses commonly occurring are Sandberg's bluegrass (*Poa sandbergii*), Thurber's stipa (*Stipa thurberiana*), bottlebrush squirreltail (*Sitanion hystrix*), and cheatgrass (*Bromus tectorum*). Generally forbs are a small constituency of relatively undisturbed communities. Common species include yarrow (*Achillea millefolium*), milkvetch (*Astragalus* spp.), fleabane (*Erigeron linearis*), woolly eriophyllum (*Eriophyllum lanatum*), and lupine (*Lupinus* spp.) (Driscoll 1964).

Figure 2.--The western juniper area in central Oregon has a savanna-like aspect.

Western juniper occurs in a wide spectrum of densities on most slopes and all aspects. Driscoll (1964b) described one association on level topography and eight associations and two variants on rolling to hilly topography (Table 1). He found slope direction limited antelope bitterbrush occurrence and influenced relative dominance of Idaho fescue and bluebunch wheatgrass. Bitterbrush occurred most commonly on east to southeast facing slopes. Idaho fescue dominated the herbaceous

Table 1. Vegetation-soil-site values illustrating the spectrum of communities studied in central Oregon and their differences (after Driscoll 1964).

Association	Association Number	Aspect	Juniper Cover (Percent)	Soil Moisture Storage (2-14")	Understory Cover (Percent)
Juoc/Artr/Feid[1]	1	NW to NE	12.0	1.41	28.5
Juoc/Artr/Feid-LUPIN	2	N to NE	12.3	1.98	24.5
Juoc/Feid	3	NW	76.7	1.81	16.7
(Bitterbrush variant)	4	(SE to E)		2.14	14.1
Juoc/Artr/Agsp-CHAEN	5	NW to NE	46.0	.87	14.9
Juoc/Artr/Agsp	6	Level	10.0	2.31	23.9
Juoc/Agsp	7	E to NE	43.0	1.34	10.5
(Bitterbrush variant)	8	(SE)			
Juoc/Artr-Putr	9	N to NE	6.6	1.54	20.8
Juoc/Agsp-Feid	10	E	32.0	.97	14.4
Juoc/Artr/Agsp-ASTRA	11	S to SW	27.7	1.21	17.4

[1] Alpha symbols for species abbreviations from Garrison et al. (1976).

layer on northerly slopes, whereas bluebunch wheatgrass tended to be dominant on southerly slopes and on level topography.

Eight of Driscoll's nine associations and both variants were considered topo-edaphic climax situations, with the other, western juniper/big sagebrush/bluebunch wheatgrass, being considered as the climatic climax association.

Much of the western juniper woodland in central Oregon occurs on level to rolling topography. Leighty's soil survey of 1362 square kilometers (526 square miles) in the heart of the juniper zone is probably one third or more of the zone we consider as occurring in the Jefferson-Deschutes County area (1958). Of this, 85 percent had slopes no greater than 7 percent. He observed that the more extensive stands of juniper woodland occurred in the southern portion of the survey area on Deschutes loamy sand and sandy loam (Xerollic camborthids), the most common soils, accounting for 22 percent of the area (Figure 2).

Two juniper sites studied by the authors near Redmond in central Oregon were identified as members of the juniper/big sagebrush/bluebunch wheatgrass association with a fenceline contrast separating them into two strikingly different condition classes due to apparent livestock disturbance. Both were on a 10 percent west slope. The undisturbed area appeared in excellent condition and the disturbed one appeared in poor to fair condition with an obvious increase in juniper, big sagebrush, and cheatgrass, and a decrease in bitterbrush, bluebunch wheatgrass, and Idaho fescue. Also, big sagebrush was present in all age classes on both sites whereas bitterbrush occurred only in a mature age class on the disturbed site (Table 2).

The soil here was mapped in the Deschutes Survey (Leighty 1958) as rough stony land, derived from Agency and Deschutes series parent materials. The former material is of sedimentary origin containing pumiceous or tuffaceous sandstones, agglomerates, gravels, sands, and ashes of parent rock containing much rhyolite and andesite. The Deschutes materials are primarily of pumiceous sand origin with some ashy materials and may contain some basalt fragments in the subsoil. Deschutes soils have weakly developed profiles, essentially sandy loam throughout with horizonation primarily the result of coloration changes and some weak lime veining. Agency soils express considerable development and are finer textured throughout than the Deschutes. Common textures in the surface and subsoil horizons are loams and clay loams, respectively, with moderate structural development in both. Lime veins occur in the lower subsoil.

Southeastern Oregon. Western juniper is generally in marginal situations in southeastern Oregon. Eckert (1957) placed juniper in relatively mesic sites on north slopes with understories primarily of big sagebrush and bunchgrass, or on rocky ridges in conjunction with

Table 2. Ecosystem values from undisturbed and disturbed sites in central Oregon.[1]

	Undisturbed				Disturbed			
	Percent Cover	Dominance	Stems/ Acre	Maximum Juoc Age	Percent Cover	Dominance	Stems/ Acre	Maximum Juoc Age
Juoc[2]	10	5	80	85	25	5	168	115
Artr	2	5	All age classes		5	5	All age classes	
Putr	2	3	All age classes		1	2	Mature only	
Gutie	1	2			-	-		
Agsp	25	5			1	3		
Feid	10	3			1	3		
Posa	3	3			3	5		
Stth	3	3			1	3		
Kocr	1	3			1	1		
Brte	1	5			2	5		
Acla	1	3			1	3		
PHLOX	1	2			1	3		
ARABI	1	1			-	-		
CALOC	1	2			-	-		
LOMAT	1	3			1	5		

1 Minor species present with equal values on both sites: Chvi, Sihy, Feoc, ASTRA.

2 Alpha symbols for species abbreviations from Garrison et al. (1976).

low sagebrush and bunchgrass. In any case juniper was quite widely spaced where it did occur. Eckert described four associations where juniper exhibited dominance. Where juniper was dominant it was interpreted as an arborescent community usually associated with escarpments and stony ridges and was considered a topo-edaphic climax. Analysis of vegetation-soil-site data showed that the only consistent differences apparent between juniper and non-juniper types were rockiness and topographic positions.

Soils supporting Eckert's associations were not correlated with named series but were in the Brown and Chestnut great soil groups. They were primarily residuum or colluvium from basalt and rhyolite with some developed on alluvial fans. Soil profiles were similar in many respects to those described by Driscoll (1964b). They were frequently rather shallow and stony with fine textured, well-developed B horizons. Some were underlain by an indurated layer cemented by calcium carbonate or siliceous materials which restricted rooting. Where the indurated layer was broken, there appeared to be an association with juniper, for example, in his western juniper/low sagebrush/Idaho fesuce association.

Southwestern Idaho. Burkhardt and Tisdale (1969, 1976) analyzed vegetation, soils, and site in two communities, one with old-growth juniper situated on shallow soils of rimrock sites, and the other with young juniper on downslope sites with deeper soils. The former was considered a topo-edapic climax community and the later a seral community (Table 3). They concluded that protection from natural fires during the last 100 years has resulted in expansion of juniper into mountain big sagebrush (*Artemisia tridentata* subspp. *vasseyana*) communities downslope from climax juniper stands which provided a seed source.

The authors concluded that under current fire control attitudes, it appears ecologically "...quite possible that the potential limit of western juniper in the study area may be the full extent of the mountain big sagebrush-Idaho fescue community or even of drier sagebrush communities" (Burkhardt and Tisdale 1976).

Table 4 displays some of the physical and chemical soil properties reported in the preceding research studies. Analytical methodology was frequently not presented in detail so the validity of the direct comparison is in question. The reader is encouraged to consult original references for further detail if such data are of particular interest. Eckert's (1957) chemical and physical soil data associated with western juniper was minor and is included in the discussion section only. He did report considerable data for soils associated with big sagebrush.

DISCUSSION

There are critical questions which must be answered before we can understand the role or potential role of western juniper in ecosystems

Table 3. Abbreviated association table of species under climax and seral juniper stands in southwestern Idaho. (after Burkhardt and Tisdale 1969)

Species	Percent Frequency																	
	Climax							Seral										
	1	2	3	4	5	13	19	6	7	11	12	14	15	16	17	18	20	21
Artrv [1]	7	3				5		3	5	45	13	40	38	31	35	43	8	36
Putr	3	3				3		8			5	3	3	3	5	8		10
Syva								8	8		3	20						25
Chvi									3	18	5					8	8	23
Agsp	18	18	18		3	18	20	15	18	23	48	45	25	58	38	30	53	68
Feid	20	43	38	13	5	30	32	40	15	40	75	78	58	10	13	45	60	73
Posa 3 (Pose)	43	60	33	40	38	52	70	65	35	100	83	43	65	65	53	83	43	38
Sihy	15	30	13	23	18	3	5	3		8			5	8		3	8	30
Stth	30	8	20	15	18	20	5								33	3	5	
Kocr								3	23	10								10
Stco								3	8			5						
Brte	5	10	45	58	33	48	3	23	23	5			15	60	100	10	80	15
Siin								5	18			3	10	13	3	3	3	63
Erpu										28	8			13		10		
Basa												5	13				13	8
Melo									5	8	20	20				15		58
Erhe										5	8				3			5
Erum								3		3				3				3
Phle												60		3				10
Asbe								8		3	5	3					3	
Lula										25	5		18					
Alac											18	3						8
Pesp								3						5	3			
Sein										3		3	10					
Erbl													10	3				3
Toru [2]	45	48	28	20	13	10	13	8	5	5		5	10			5		20

[1] Alpha symbols for species abbreviations from Garrison et al. (1976).

[2] <u>Tortula ruralis</u> (Moss)

Table 4. Soil characteristics in western juniper zone exemplary of findings by various researchers.

Source, Horizon or depth (inches), community or other	pH	Organic Matter	Extractable Bases					Cation Exchange Capacity	Base Saturation	Avail-able P	Total N	Organic C/N	Bulk Density	Soil Moisture Storage in 2-14 inch zone
			Ca	Mg	Na	K	Total							
	--	%	Me/100g					Me/100g	%	ppm	%	--	g/cc	inches
Driscoll (1964) A horizons														
Juoc/Artr/Feid[1]		4.78								--	.21	13	--	1.4
Juoc/Feid		3.91								--	.17	12	--	2.0
Juoc/Artr/Agsp		1.50								--	.08	11	--	2.3
Juoc/Agsp		2.12								--	.10	12	--	1.3
Juoc/Agsp-Feid		1.32								--	.07	11	--	1.0
Juoc/Artr/Agsp-ASTRA		1.63								--	.08	12	--	1.2
Dealy and Geist (Redmond, Oregon area, (Juoc/Artr/Agsp)														
Disturbed 0-6	5.9	2.0	20.6	11.0	0.2	1.3		--	--	6.4	.20	6	--	--
6-12	6.4	1.7	34.4	21.8	0.3	1.5		--	--	1.6	.12	9	--	--
12-18	7.3	1.5	81.3	21.7	0.6	1.2		--	--	2.0	.22	5	--	--
Undisturbed 0-6	6.3	2.1	21.6	9.2	0.2	1.3		--	--	8.0	.13	9	--	--
6-12	6.6	1.7	38.3	17.7	0.3	1.4		--	--	2.5	.11	9	--	--
12-18	7.3	1.5	84.5	18.8	0.4	1.2		--	--	2.1	.19	5	--	--
Burkhardt and Tisdale (1969)														
Climax Soils All horizon	7.0	--	8.8	--	--	--	--	14	83	--	--	--	1.50	--
B2	6.4	--	5.5	--	--	--	--	12	76	--	--	--	1.60	--
C	--	--	--	--	--	--	--	--	--	--	--	--	1.69	--
Seral Soils All	6.4	--	9.0	--	--	--	--	19	71	--	--	--	1.23	--
B2	6.5	--	7.0	--	--	--	--	14	79	--	--	--	1.56	--
C	6.5	--	--	--	--	--	--	--	81	--	--	--	1.54	--

1 Alpha symbols for species abbreviations from Garrison et al. (1976).

of the Intermountain Northwest. For example:

1. What is juniper's potential distribution among ecosystems?

2. What is juniper's potential competition among ecosystems?

3. What is its successional status?

4. What is the influence of fire or lack of it under various site conditions and on distributions and density?

Present distribution of western juniper, its current densities and age structure tell us little about these questions. Valuable work has been done in central Oregon (Driscoll 1962, 1964a, 1964b, Leighty 1958, Adams 1975), in southeastern Oregon (Eckert 1957), and southwestern Idaho (Burkhardt and Tisdale 1969, 1976) on certain phases of western juniper ecology. However, only the surface of knowledge on this subject has been scratched. There have been several authors who place western juniper in the position of invader and/or successional component in some ecosystems (Burkhardt and Tisdale 1969, 1976, Anderson 1956). Burkhardt and Tisdale (1976) developed strong historical evidence that fire prevented spread of juniper from relic or old topo-edaphic climax communities on rocky ridges and rimrocks. In our study in central Oregon, higher density of juniper in the disturbed area appeared related to reduced competition by overgrazing because both sites were equally vulnerable to fire and neither community had stands of old-growth juniper, but had similar maximum stand ages. Actual presence of juniper was possibly a result of fire protection.

Some of Driscoll's (1964b) communities had young stands of juniper which he related to fire but did not consider as seral to big sagebrush. It is difficult to consider western juniper in a subordinate role, successionally, to a shrub such as this. It is, however, acceptable to the authors to consider a big sagebrush community as held in a successional stage by short fire cycles, disallowing juniper its full expression as the climax dominant. Burkhardt and Tisdale (1976) found no evidence of fire in the stand of juniper they considered seral and thus considered the occurrence of juniper in this community to have begun 88 years ago in the absence of fire. It is reasonable that a fire cycle could historically have allowed juvenile juniper stands to become established only to be later obliterated. Thus, we would have in reality a juniper site where young juniper stands occur periodically but are kept from full expression because of fire. In other words, the ecosystem might be considered in a pyroclimatic situation. Further, because of distance to seed source and lack of seed carrying bird populations, large areas of mountain big sagebrush having no evidence of juniper occurrence may actually be potential juniper sites. Burkhardt and Tisdale (1969) suggested this type in general may be suitable for juniper establishment. We believe the important thing is to recognize

juniper in its fullest potential expression so managers are not continually shocked or surprised when this species pops up in a "new" situation. Managers tend to consider it a "weed" which is out of place, when in reality it may only be changes in management (e.g., fire control or overgrazing) which produce an unfamiliar situation.

With knowledge of western juniper's potential expression, we as managers and scientists can develop and provide guides to insure intelligent management of this species.

Even a brief personal encounter with variability in soils, climate, topography, management history, vegetation, etc. conveys the complexity of unravelling the ecology of western juniper areas.

There are no simple rules of thumb to present in summing up vegetation-soil-site relationships in the western juniper zone. Juniper is not uniquely associated with a fixed set of soil conditions, a soil series, type or phase nor even a strongly related set of soils as we now view our knowledge. Effective moisture is probably the main factor determining the potential of a site for juniper.

Some conditions appear more conducive to juniper occurrence than others but we now lack the ability to define the limits of those conditions and their combinations. Combination is a key concept here as is compensation. Juniper seems to grow reasonably well in deep, well-drained, medium to coarse textured soils or in shallow soils of poorly structured, heavy textured subsoils with higher coarse fragment percentages and fractured bedrock. Apparently clayey subsoil zones and/or accessibility to deep moisture in bedrock fissures can compensate for a shortage in moisture storage in shallow soils. This is but one example of seemingly numerous compensating soil-site factors over the zone.

Burkhardt and Tisdale (1976) suggest deeper soils of valley bottoms are most conducive to seedling establishment in contrast to shallower, better drained soils being most conducive to growth after establishment. Eckert (1957) suggests that western juniper is a species requiring relatively high amounts of moisture and that the requirement may be met by a number of compensating factors.

Some rather exclusive vegetation relationships are in evidence between western juniper and other species, and we speculate that more could be found if specifically sought. Eckert (1957) noted Cusick tickweed (*Hackelia Cusikii*) to exist only under juniper crowns. We have observed association of grass species such as Idaho fescue on one side of the crown perimeter but not on others. Eckert further noted that cover of Idaho fesuce and moss (*Tortula ruralis*) deteriorate with death of the associated juniper individual. Burkhardt and Tisdale (1969) also noted a greater abundance of moss under older trees.

The above relationships appear closely related to soils. Eckert noted that soil surface pH under older juniper crown averaged 1.0 unit higher than bare soil interspaces and under shrub crowns. He added that associated herbaceous species may contribute to this influence. He found no increased salinity levels associated with pH increases. Burkhardt and Tisdale found higher average soil pH and percentage base saturation values associated with climax juniper stands compared to "seral" stands. These data raise an important question about the significance of nutrient cycling differences associated with western juniper and their relation to companion species composition, growth, and synecology.

Possible differential nutrient cycling is not unique to juniper systems. Geist (unpublished data) found soil nutrient differences under shrub versus non-shrub vegetative components in eastern Oregon as have other workers in southeastern Washington (Rickard et al. 1973). The latter workers followed up their findings with bioassays which showed cheatgrass growth was greater and higher in nitrogen when grown in shrub-influenced soil than in interspace soil.

There are some important vegetation-soil-site relationships to be gleaned from research of other juniper species. Clary and Morrison (1973) found that essentially all early spring forage in central Arizona was produced under crowns of large alligator juniper (Juniperus deppeana) trees and they cautioned managers about potential forage loss with removal of these trees in "control" projects.

Jameson (1970) reported that seedling growth-inhibiting substances were present in fresh leaves, litter and humus from Utah juniper (Juniperus osteosperma) which affected blue grama (Bouteloua gracilis) germination. He noted this influence was primarily associated with poorly aerated soils.

Hence, we see that soil and plant chemical factors associated with juniper, juniper companion species, or both must be recognized if we are to properly interpret species interactions. These factors should be included when analyzing plant communities both for the purpose of establishing range trend and for management evaluation.

Published data and personal experiences with highly contrasting indicator species on seemingly homogeneous soils and sites makes us aware of the difficulty in defining unique vegetation-soil units in some cases. Eckert (1957) reports that in western juniper/low sagebrush communities where a juniper tree dies, big sagebrush becomes established around the dead tree. Further investigation showed soil under the tree was considerably deeper than under low sagebrush and was better suited to juniper or big sagebrush. Our personal experience with a bitterbrush-low sagebrush complex was similar in central Oregon near Silver Lake, where deeper soil favored bitterbrush (unpublished data).

Hence, vegetation indicators may be misleading to managers without associated soil data. Therefore, we must be cautious in choosing where and what benefits may be gained in juniper stand management.

RESEARCH AND MANAGEMENT

Research Objectives

Determine:

1. Influence of fire on the distribution and density of juniper.

2. Optimum soil-site conditions for juniper.

3. Successional ecology of western juniper in the core area of central Oregon to aid in relating seral understory stages to potential plant communities.

4. Localized influence of juniper presence on species composition, nutrient cycling, and current and potential productivity particularly regarding control of juniper expansion.

5. Age structure of western juniper in the core woodland area of central Oregon.

6. The effect of variable juniper density on forage production and other resource values, e.g., wildlife, water yield and storage, and erosion.

Management Implications

1. Juniper has a localized influence on soil properties, plant composition, and forage productivity:

   a. Under crown vs outside crown
   b. North side vs south side of crown

2. Localized influences must be recognized in sampling vegetative changes following removal of juniper in order to separate effects due to its absence and that due to other factors.

3. Soil removal or displacement in juniper control programs can greatly alter the potential plant community since soil depth is frequently marginal for many existing communities. Managers should know soils and possible localized effects on the resulting mosaic of plant communities.

4. SCS range site classficiation data should be used to refine vegetation relationships to identified soils. Such information will provide predictive insights to the spread of juniper to sites currently unoccupied by trees.

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WESTERN JUNIPER IN ASSOCIATION WITH OTHER TREE SPECIES

Frederick C. Hall, Regional Ecologist
U.S. Forest Service, Portland, Oregon

ABSTRACT

Juniper plant communities occur within the forest zone on shallow, stony soils with moderately cracked bedrock. A perched water table is common during the winter. Desert pavement on the soil surface is common. Four kinds of plant communities are described: juniper/bunchgrass, juniper/low sage/bunchgrass, juniper/low sage/scabland, and juniper/stiff sage/scabland.

Keywords: Plant communities, soil description, bedrock, desert pavement, range condition, revegetation.

INTRODUCTION

Drs. Ed Dealy and Jon Geist have discussed western juniper plant communities as they occur within the general climatic zone for juniper. This paper discusses juniper occurrence within the forest zone. It is divided into two parts: the concept of why juniper grows within the forest zone and kinds of juniper plant communities with some of their characteristics.

CONCEPTS OF FOREST ZONE JUNIPER

The concept of forest zone used here is the same as general ecology textbook definitions. It extends from the edge of ponderosa pine (*Pinus ponderosa*) at lower elevations through Douglas-fir (*Pseudotsuga menziesii*) and true fir types (*Abies concolor*, *A. grandis*) ending at subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pine albicaulis*), or mountain hemlock (*Tsuga mertensiana*) forest at upper elevations. In central Oregon, this zone starts about 3500 feet and extends up to 7500 feet elevations.

The change from juniper zone to forest zone is traditionally marked by an intergrade between juniper and ponderosa pine. Typical examples occur in and east of Sisters, Oregon and around Bend. The criteria for defining a "juniper type" compared to a "ponderosa type" is established by individual investigators. Regardless of the criteria used, some juniper types adjacent to the forest zone will contain occasional individuals of ponderosa pine, and ponderosa stands at the lower edge of the

forest zone will invariably contain individual juniper trees. Some people consider the transition from juniper to pine important and give it habitat type status such as Ponderosa-Juniper/Big sage/Bunchgrass.

In addition, juniper seems to be a good competitor and is sensitive to underburning. Many ponderosa stands have been maintained in pine by underburning. They are now gradually shifting to a Douglas-fir or true fir climax with fire suppression. We commonly find occasional young juniper trees in these stands. Juniper appears to compete reasonably well with Douglas-fir and sometimes true fir until crown cover becomes too dense.

The real point of this paper, however, is discussion of plant communities within the forest zone which are clearly dominated by western juniper (Hall, 1973). My criteria for a "juniper type" is two or more trees per acre. Using this criteria, juniper types in the forest zone are common in the Blue Mountains and occur with reasonable frequency in and around the Fremont National Forest. They are uncommon in the Deschutes and Winema Forests on pumice soils (Volland, 1976) and they seldom occur on the east slope of the Washington Cascades.

Juniper seems to dominate on what might be termed environmentally drier sites within the forest zone. They usually have shallow, stony soil with moderately cracked bedrock. A perched water table during the winter seems to be common. The soil's surface is often covered by desert pavement.

Desert pavement is not "erosion pavement" (Springer, 1958). Desert pavement is a natural phenomenon caused by freezing and thawing as well as wetting and drying of the surface soil. It is characterized by a pavement of gravel ranging from 1/8 inch to 2 inches diameter overlying a vesicular A horizon 1 to 2 inches thick. The A horizon is free of gravel because frost heaving has moved gravel out of the soil and onto the soil surface. Soil below 1 to 2 inches commonly contains gravel. Naturally occurring desert pavement is desirable because it breaks up raindrop impact, greatly reduces wind erosion of fine particles, reduces surface water movement of fine particles, and reduces soil surface erodibility under freezing-thawing situations. "Erosion pavement" is the result of surface soil erosion in which fine particles have been removed by wind and/or water, leaving gravel. The soil 1 to 2 inches under it is not vesicular and usually contains a reasonable amount of gravel. Thus erosion pavement and desert pavement can be differentiated in the field.

Juniper plant communities above the ponderosa pine zone, within the Douglas-fir or true fir zones, tend to have dramatically different soil and bedrock characteristics from forest stands. Intergrades between the two are seldom encountered.

FOREST ZONE JUNIPER TYPES

Four major kinds of juniper plant communities will be discussed. The order of presentation will be: soil-site description, herbage description and production, revegetation characteristics, and when needed a general discussion.

Juniper/bunchgrass

This type is most common in the central Blue Mountains. Soils are 8 to 18 inches deep, stony to very stony silt loam to clay loam. Bedrock is moderately broken. Desert pavement and a winter perched water table are common.

Herbage dominants are bluebunch wheatgrass (*Agropyron spicatum*) and/or Idaho fescue (*Festuca idahoensis*) with reasonably abundant Sandberg bluegrass (*Poa sandbergii* var. *secunda*). Needlegrass (*Stipa* spp.), squirreltail (*Sitanion hystrix*), and junegrass (*Koeleria cristata*) are common. Cheatgrass (*Bromus tectorum*) tends to do poorly on the site because shallow, stony soil and a winter perched water table due to restricted subsoil drainage are detrimental to good cheatgrass establishment and growth. Lomatiums (*Lomatium* spp.) are common in poor range condition. Average herbage production is 250 to 500 pounds per acre. A major portion of this in good range conditions is contributed by wheatgrass and fescue.

Revegetation opportunities are limited by soil characteristics. Deeper soils, less stony soils, and darker soils are best revegetation opportunities. The crested wheatgrass (*Agropyron cristatum*, *A. desertorum*) group of domestic plants are most suitable for this site. In addition, lack of abundant old-growth juniper and presence of younger-age classed juniper suggest better sites. In general, abundant old-growth juniper indicate a site inherently so poor that ground fires either have not been common or have not been of sufficient intensity to eliminate juniper.

Juniper/low sagebrush types

Low sagebrush (*Artemisia arbuscula*) is a common shrub dominant under juniper in the Blue Mountains and in the Fremont National Forest area. Unfortunately, it is not a real good indicator of site potential. It does indicate a site poorer than those areas dominated by big sagebrush (*Artemisia tridentata*). However, it tolerates environmental conditions ranging from good bunchgrass productivity down to scabland. The two following types are used to illustrate this relationship.

Juniper/low sage/bunchgrass

The site is very similar to Juniper/bunchgrass, but this plant community occurs in the southern Blue Mountains and on the Fremont. Soils are 8 to 18 inches deep, stony, silt loam to clay loam, over moderately cracked bedrock. A perched water table during the winter is common. At lower elevations, a well cracked bedrock tends to support Ponderosa/wheatgrass, Ponderosa/big sage/wheatgrass, or Ponderosa/low-sage/wheatgrass.

Understory vegetation in good range condition is dominated by low sagebrush of 2 to 10 percent crown cover. Wheatgrass and/or Idaho fescue are dominant with Sandberg's bluegrass. Needlegrass, squirreltail, and junegrass are also common. Cheatgrass does poorly on this site. Herbage production ranges from 350 to 500 pounds in good condition. Tueller (1962) evaluated reaction of sagebrush to overgrazing. He found that sagebrush does not tend to increase significantly.

Revegetation on this type can take either of two forms: sagebrush control, or seeding of grass. Low sage can be reduced in crown cover by spraying, burning, or other treatment. However, it tends to be palatable to big game. Since this type often occurs in winter or spring-fall game range areas, each case of sagebrush control should be carefully considered. Deeper, darker soils respond best to seeding. However, the site is generally poor and response to the crested wheatgrass group of plants is moderately low to low.

Juniper/low sage/sandberg bluegrass scabland

Old growth juniper is always present on the low sage/scabland plant community type. It is one means of separating the juniper/low sage/scabland from juniper/low sage/bunchgrass types. Soils are less than 8 inches deep, stony, on moderately cracked bedrock. When bedrock cracking becomes moderately fine to fine, a low sage/scabland without juniper seems to result. Desert pavement is always present in good soil condition and is highly desirable.

Wheatgrass and Idaho fescue are generally absent (or very low in dominance) in good range condition. Instead, Sandberg bluegrass and one-spike oatgrass (*Danthonia unispicata*) are dominant. These plants, increasers in other juniper types, should be classified as decreasers in this plant community. Cheatgrass is absent in poor range condition because the site is much too poor. Instead, Lomatiums tend to be common. Herbage production in good range condition varies from 150 to 300 pounds per acre.

Revegetation is not feasible because the site is too poor. In most cases, the crested wheatgrass group of plants cannot withstand this kind of site. A perched water table is always present during part

of the winter. On the other hand, soils dry to wilting point by the first to the middle of July. Fluctuation from standing water to wilting point within the soil greatly limits plant species adapted to the site.

These two types characteristically occur in the southern Blue Mountains and in the Fremont National Forest area. They are an excellent example of end points in a continuum between vegetation types. As soil depth changes from 6 to 12 inches, good range condition changes from a dominance of bluegrass-oatgrass to wheatgrass-fescue, herbage production changes from 150 to 450 pounds, desert pavement changes from always present and continuous to often present and not continuous. At soil depths of 7 to 10 inches, wheatgrass and fescue can colonize the site but in limited density. They tend to become ice cream plants in comparison to bluegrass and oatgrass. At 10 to 12 inches soils depth, wheatgrass and fescue become dominant enough to carry sufficient livestock grazing that they can be considered decreasers.

If all ranges were in good condition, we would have little trouble evaluating where on this continuum gradient a site might lie. However, recognition of site quality in poor range condition is difficult. Juniper/low sage/scabland sites can be differentiated from wheatgrass-fescue sites by considering the following: Scabland types have no cheatgrass or yarrow (*Achillea millefolium*) in poor condition; a greater proportion of juniper trees show old-growth form (diameter at a 12 inch stump is greater than 10 inches); nearly continuous cover of desert pavement; reddish hue to soil color instead of a brownish cast: soil surface moderately stony to stony; bedrock occasionally to commonly exposed; and of course, soil depth 8 inches or less.

Juniper/stiff sage/bluegrass scabland

This is the most common juniper/scabland type in the Blue Mountains. For some reason, it is seldom found elsewhere; it is replaced in the Fremont area by juniper/low sage/scabland. Soils are less than 8 inches deep, stony, silt loam to clay loam, over moderately cracked bedrock, and have a winter perched water table. Fine to moderately fine cracked bedrock results in no juniper. Desert pavement is almost continuous in good range condition.

Stiff sage (*Artemisia rigida*) occurs at 2 to 10 percent crown cover. It has a deeply three-cleft leaf that looks rather similar to three-tipped sage (*Artemisia tripartita*). However, the key identifying characteristic of stiff sage is its deciduous nature. This separates it from any other three-tipped sage found in the Pacific Northwest. Stiff sage is an excellent indicator of scabland. Herbaceous vegetation is dominated by Sandberg's bluegrass, one-spike oatgrass, and often bighead clover (*Trifolium macrocephalum*) in good range condition. Cheatgrass and yarrow are absent in poor range condition due to site limitations. Poor

condition commonly is dominated by Lomatiums. Herbage production ranges from 150 to 250 pounds per acre.

Revegetation is not feasible because the site is too poor. Stiff sage is highly palatable to big game and livestock. Sage seedheads in August and September seem to be a prized forage. The low, compact shape of stiff sage is a result of grazing rather than the natural life form of this shrub.

SUMMARY

Juniper types within the forest zone in the Pacific Northwest are topo-edaphic climaxes. They occur on rather precise limits of shallow, stony soil overlying moderately cracked bedrock. These are environmentally drier sites than the associated forest. A perched water table during winter is almost universal. Due to site restrictions, forage production tends to be limited and revegetation is questionable to undesirable.

Juniper does occur in ponderosa pine stands at the lower edge of the forest where the pine and juniper zones meet. In addition, young juniper are often found in open pine, fir, or associated forests probably as a result of fire suppression.

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INTERRELATIONSHIPS OF WILDLIFE AND WESTERN JUNIPER

Chris Maser, USDI Bureau of Land Management,
La Grande, Oregon
and
Jay S. Gashwiler, USDI Fish and Wildlife Service
(Retired), Bend, Oregon

ABSTRACT

The structure of a western juniper tree changes as it matures increasing available opportunities or niches for wildlife use. In most cases, juniper habitat in central Oregon supports larger bird populations and more species than does ponderosa pine, lodgepole pine, or big sagebrush habitats. The western juniper habitat apparently creates a relatively benign environment for many species of wildlife. A provisional list of wildlife that utilizes western juniper includes 83 species of birds and 23 species of mammals. The western juniper community can be improved for wildlife by development of water impoundments, openings, and placement of bird nesting and roosting boxes. The most pressing wildlife research needed in western juniper communities are: (1) inventories of wildlife, (2) wildlife use of individual trees and of the communities as a whole, and (3) effects of manipulation of western juniper communities on wildlife.

Keywords: Western juniper, birds, mammals.

INTRODUCTION

So far as we have been able to determine, little work has been done on the interrelationships of wildlife and western juniper[2] in Oregon.

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[2] Due to the number of scientific names in this paper that will be largely unfamiliar to managers, common and scientific names used in the text are given in Appendix 1.

Neither Bailey's (1936) study of Oregon mammals nor Gabrielson and Jewett's (1940) study of Oregon birds took the western juniper community into account per se. However, this community is defined and discussed by Driscoll (1964) and Franklin and Dyrness (1973) so we will not repeat it here. Our objective is to discuss the structure and function of western juniper as it pertains to those species of wildlife that utilize it--some opportunistically, some dependently. Opportunistic use of juniper is defined as utilization when it is available, but the presence or absence of the trees does not dictate the presence or absence of the animal, e.g., the ubiquitous deer mouse. An animal's dependence upon juniper is denoted by its presence in an area only so long as juniper is available. For example, the yellow pine chipmunk (Fig. 1) is primarily an inhabitant of pine forests, but in the absence of pine it will occur in an area where juniper is present. Some species, such as the bushy-tailed woodrat, may be independent of juniper in areas where cliffs, rim-rocks, or talus occur, but dependent upon juniper in areas where these structures are absent.

Figure 1.--Yellow pine chipmunk, Cabin Lake, Lake County, Oregon (U.S. Fish and Wildlife Service photograph by J. S. Gashwiler).

THE WESTERN JUNIPER COMMUNITY

Structure and function

Western juniper changes in structure as it matures (Burkhardt and Tisdale 1969, Sowder and Mowat 1958); these changes provide different uses of an individual tree for wildlife. The number and types of uses increase or change as a tree matures (Table 1). Due to the considerable variation between individual trees, the following discussion is generalized.

The seedling: The small seedling, < 1 m tall with its sparse foliage provides two basic functions. For small animals it can be used as shade or wind protection, but not as hiding cover. Its foliage may also be used as food.

The sapling: A sapling, 1 to 2 m tall with a crown reaching to the ground, is large enough to provide both hiding and thermal cover and food for some animals. A young tree without a full-length crown provides primarily forage and thermal cover. It is often used by some species of birds as a singing or perching tree and is occasionally used for nesting.

The young-mature tree: A mature juniper > 2 m tall is large enough that birds and mammals can nest in it and primary cavity nesters can excavate in dead portions of the trunk. With a full-length crown, a tree offers both thermal and hiding cover for large animals. The trunk, limbs, and crown are large enough to sustain birds that feed by gleaning (searching for) insects. Berry crops, though not regular, are a substantial source of food for birds and mammals. A mature tree is also tall and stout enough for raptorial birds to use as a perch.

The decadent tree: As a juniper becomes decadent, its top starts to break apart and the trunk and limbs frequently become hollow. These natural cavities form protected sites in which some birds and mammals rear their young and rest. Bats may use them for hibernation sites. When a hollow tree dies and falls to the ground, it offers shelter and lookout sites for ground-dwelling mammals. If a stump remains, it is similarly utilized.

In a juniper community composed of trees representing all-age groups, a diversity of reproductive and feeding habitats and protective cover for both opportunistic and dependent wildlife are present.

Habitat diversity

We recognize that the western juniper community abutts pine forests in many areas, but the structural contrast is not as great as the ecotone between juniper and sagebrush range types. Furthermore, habitat diversity is magnified in localities where juniper stands are isolated from other forested communities. We have confined our discussion to the structural

Table 1. Provisional wildlife use of different aged western juniper trees. (These data are based largely on the authors' interpretations of information taken from several sources.)

Species	Young	Mature	Old and decadent	Stumps and downed logs	Source
BIRDS					
VULTURES					
Turkey vulture			X		Gashwiler (Notes and Obs.)
HAWKS and EAGLES					
Goshawk		X	X		Gashwiler (Notes and Obs.)
Cooper's hawk		X	X		Gashwiler (Notes and Obs.)
Sharp-shinned hawk		X	X		Gashwiler (Notes and Obs.)
Marsh hawk					
Ferruginous hawk		X	X		Gabrielson and Jewett (1940) Gashwiler (Notes and Obs.)
Red-tailed hawk		X	X		Gashwiler (Notes and Obs.) Jewett (1936)
Swainson's hawk			X		Gashwiler (Notes and Obs.)
Golden eagle			X		Gashwiler (Notes and Obs.)
FALCONS					
Prairie falcon		X	X		Gashwiler (Notes and Obs.)
BIRDS					
American kestrel		X	X		Gashwiler (Notes and Obs.)
Merlin		X	X		Gashwiler (Notes and Obs.)
GROUSE					
Sage grouse		X	X		Gashwiler (Notes and Obs.)
QUAILS, PARTRIDGES, and PHEASANTS					
California quail		X	X		Gashwiler (Notes and Obs.)
Chukar					
PIGEONS and DOVES					
Mourning dove		X	X		Gashwiler (Notes and Obs.)
OWLS					
Screech owl		X	X		Maser (Notes and Obs.)
Great horned owl		X	X		Gashwiler (Notes and Obs.)
GOATSUCKERS					
Common nighthawk		X	X		Gashwiler (Notes and Obs.)

Table 1. Provisional wildlife use of different aged western juniper trees. (These data are based largely on the authors' interpretations of information taken from several sources.)(Continued)

Species	Young	Mature	Old and decadent	Stumps and downed logs	Source
BIRDS					
HUMMINGBIRDS					
Rufous hummingbird		X	X		Gashwiler (Notes and Obs.)
WOODPECKERS					
Common flicker			X	X	Gashwiler (Notes and Obs.)
Lewis' woodpecker			X		Bent (1964a), Gashwiler (Notes and Obs.)
Yellow-bellied sapsucker		X			Maser (Notes and Obs.)
TYRANT FLYCATCHERS					
Western kingbird					
Ash-throated flycatcher		X	X		Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Say's phoebe					
Dusky flycatcher		X	X		
Gray flycatcher		X	X		Gashwiler (Notes and Obs.)
SWALLOWS					
Barn swallow			X		Gashwiler (Notes and Obs.)
BIRDS					
Cliff swallow			X		Gashwiler (Notes and Obs.)
Tree swallow			X		Gashwiler (Notes and Obs.)
JAYS, MAGPIES, and CROWS					
Steller's jay		X	X		Gashwiler (Notes and Obs.)
Pinyon jay		X	X		Gashwiler (Notes and Obs.)
Black-billed magpie		X	X		Gashwiler (Notes and Obs.)
Clark's nutcracker		X	X		Gashwiler (Notes and Obs.)
Common raven		X	X		Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Common crow					
CHICKADEES and BUSHTITS					
Black-capped chickadee					
Mountain chickadee		X	X		Gashwiler (Notes and Obs.)
Bushtit	X	X			Gashwiler (Notes and Obs.), Maser (Notes and Obs.)

Table 1. Provisional wildlife use of different aged western juniper trees. (These data are based largely on the authors' interpretations of information taken from several sources.)(Continued)

Species	Young	Mature	Old and decadent	Stumps and downed logs	Source
BIRDS					
NUTHATCHES					
Red-breasted nuthatch		X	X		Gashwiler (Notes and Obs.)
Pygmy nuthatch		X	X		Gashwiler (Notes and Obs.)
CREEPERS					
Brown creeper					
WRENS					
Rock wren		X	X		Gashwiler (Notes and Obs.)
MOCKINGBIRDS and THRASHERS					
Sage thrasher	X	X	X		Gashwiler (Notes and Obs.)
THRUSHES, SOLITAIRES, and BLUEBIRDS					
American robin		X	X		Gashwiler (Notes and Obs.)
Townsend's solitaire		X	X		Gashwiler (Notes and Obs.)
Hermit thrush					
BIRDS					
Western bluebird		X	X		Gashwiler (Notes and Obs.), Maser (Notes and Obs.)
Mountain bluebird		X	X		Gashwiler (Notes and Obs.)
GNATCATCHERS and KINGLETS					
Ruby-crowned kinglet		X	X		Gashwiler (Notes and Obs.)
WAXWINGS					
Bohemian waxwing		X	X		Gashwiler (Notes and Obs.)
Cedar waxwing		X	X		Gashwiler (Notes and Obs.)
SHRIKES					
Northern shrike	X	X			Gashwiler (Notes and Obs.)
Loggerhead shrike	X	X			Gashwiler (Notes and Obs.)
STARLINGS					
Starling			X		Gashwiler (Notes and Obs.)
WOOD WARBLERS					
Orange-crowned warbler					

Table 1. Provisional wildlife use of different aged western juniper trees. (These data are based largely on the authors' interpretations of information taken from several sources.)(Continued)

Species	Young	Mature	Old and decadent	Stumps and downed logs	Source
BIRDS					
Yellow-rumped warbler		X	X		Gashwiler (Notes and Obs.)
Townsend's warbler		X	X		Gashwiler (Notes and Obs.)
Black-throated gray warbler		X	X		Gashwiler (Notes and Obs.)
Wilson's warbler		X			Gashwiler (Notes and Obs.)
BLACKBIRDS and ORIOLES					
Western meadowlark	X	X			Gashwiler (Notes and Obs.)
Brewer's blackbird		X			Gashwiler (Notes and Obs.) Maser (Notes and Obs.)
Red-winged blackbird					
Brown-headed cowbird		X	X		Gashwiler (Notes and Obs.)
Northern oriole		X			Gashwiler (Notes and Obs.)
TANAGERS					
Western tanager		X	X		Gashwiler (Notes and Obs.)
BIRDS					
GROSBEAKS, FINCHES, SPARROWS, and BUNTINGS					
Evening grosbeak		X	X		Gashwiler (Notes and Obs.)
Lazuli bunting					
Purple finch		X	X		Gashwiler (Notes and Obs.)
Cassin's finch		X	X		Gashwiler (Notes and Obs.)
House finch		X	X		Gashwiler (Notes and Obs.)
Green-tailed towhee	X	X			Gashwiler (Notes and Obs.)
Rufous-sided towhee					
Vesper sparrow					
Black-throated sparrow					
Lark sparrow					
Dark-eyed junco		X	X		Gashwiler (Notes and Obs.)
Chipping sparrow	X	X	X		Gashwiler (Notes and Obs.)

Table 1. Provisional wildlife use of different aged western juniper trees. (These data are based largely on the authors' interpretations of information taken from several sources.)(Continued)

Species	Young	Mature	Old and decadent	Stumps and downed logs	Source
BIRDS					
Brewer's sparrow	X	X			Gashwiler (Notes and Obs.)
White-crowned sparrow		X			Gashwiler (Notes and Obs.)
Lincoln's sparrow		X	X		Gashwiler (Notes and Obs.)
Song sparrow					
MAMMALS					
BATS					
Little brown myotis		X	X		Maser (Notes and Obs.)
Long-eared myotis		X	X		Bailey (1936), Maser (Notes and Obs.)
California myotis		X	X		Maser (Notes and Obs.)
Silver-haired bat		X	X		Hansen (1956), Maser (Notes and Obs.)
Big brown bat		X	X		Maser (Notes and Obs.)
Hoary bat		X	X		Bailey (1936)
RABBITS and HARES					
Mountain cottontail	X	X	X	X	Maser (Notes and Obs.)
MAMMALS					
Black-tailed jackrabbit	X	X	X	?	Maser (Notes and Obs.)
RODENTS					
Yellow pine chipmunk		X	X	X	Kindschy (1976), Maser (Notes and Obs.)
Townsend ground squirrel				X	Gashwiler (Notes and Obs.)
Mantled ground squirrel		X	X	X	Kindschy (1976), Maser (Notes and Obs.)
Deer mouse	X	X	X	X	Maser (Notes and Obs.)
Pinyon mouse		X	X	?	Baker and Frischknecht (1973), Gashwiler (Notes and Obs.)
Dusky-footed woodrat		X	X	X	Hammer and Maser (1973)
Bushy-tailed woodrat		X	X	X	Hammer and Maser (1973), Maser (Notes and Obs.)
Porcupine		X	X	?	Maser (Notes and Obs.)
CARNIVORES					
Coyote	X	X	X	?	Maser (Notes and Obs.), Shaver (1976)
Long-tailed weasel		X	X	X	Maser (Notes and Obs.)

Table 1. Provisional wildlife use of different aged western juniper trees. (These data are based largely on the authors' interpretations of information taken from several sources.)(Continued)

Species	Young	Mature	Old and decadent	Stumps and downed logs	Source
MAMMALS					
Spotted skunk		X	X	X	Maser (Notes and Obs.)
Bobcat		X	X	?	Maser (Notes and Obs.) Shaver (1976)
EVEN-TOED MAMMALS					
Elk	X	X			Leckenby (1976)
Mule deer	X	X	X		Leckenby and Adams (1976), Maser (Notes and Obs.)
Pronghorn	X	X	X		Leckenby (1976), Dealy (1977)
Subtotal Birds	8	58	56	1	
Subtotal Mammals	7	22	21	9	
Total	15	80	77	10	

diverstiy of sagebrush vs juniper communities in Oregon.

There is great variation within sagebrush communities (Adams 1975, Culver 1964, Dealy 1971, Eckert 1957, Hall 1967), but they all have shrubs as the structurally dominant plant (Fig. 2). Without the structural diversity of associated cliffs, rimrocks, talus, or water, only five "Life Forms" (Thomas et al. 1976) (Table 2) occupy these sagebrush communities: Life Form 5, 6, 7, 8, and 15. Within sagebrush communities, the presence of suitable cliffs, rimrocks, or talus, particularly when situated within 0.4 to 0.8 kilometer of water, adds Life Form 4.

Figure 2.--Big sagebrush habitat, Whitehorse Ranch Road, Malheur County, Oregon (photograph by C. Maser).

The western juniper community (Fig. 3) adds increased structure by the nature of the trees, individually and collectively. Presence of this community allows the addition of four more Life Forms: 11, 12, 13, and 14. Furthermore, the edge between the sagebrush and juniper communities creates additional diversity (Fig. 4).

Table 2. Description of vertebrate life forms occurring in the Blue Mountains (Thomas et al. 1976).

Life form number	Reproduces	Feeds
1	in water	in water
2	in water	on ground, in bushes and/or trees
3	on ground around water	in water, on ground, in bushes, and trees
4	in cliffs, caves, rims and/or talus	on ground or in air
5	on ground without specific water, cliff, rim, or talus association	on ground
6	on ground	in bushes, trees, or air
7	in bushes	on ground, in water or air
8	in bushes	in bushes, trees, or air
9	primarily in deciduous trees	in bushes, trees, or air
10	primarily in conifers	in bushes, trees, or air
11	in trees	on ground, in bushes, trees, or air
12	on very thick branches	on ground or in water
13	excavates own hole in a tree	on ground, in bushes, trees, or air
14	in a hole made by another species or naturally occurring	on ground, in water, or air
15	underground burrow	on or under ground
16	underground burrow	in water or air

Figure 3.--Western juniper habitat, Horse Ridge Research Natural Area, Deschutes County, Oregon (U.S. Fish and Wildlife Service photograph by J. S. Gashwiler).

Figure 4.--Ecotone between western juniper and big sagebrush communities, Horse Ridge Research Natural Area, Deschutes County, Oregon (photograph by C. Maser).

WILDLIFE USES OF WESTERN JUNIPER

Due to the large number of vertebrate animals (birds, Table 3, and mammals, Table 4) that utilize juniper, the following is a general discussion.

Birds

Importance of western juniper habitat: A recent 3-year study was conducted to compare bird populations among relatively undisturbed big sagebrush, western juniper, lodgepole pine, and ponderosa pine habitats in central Oregon (Gashwiler 1977). The investigations showed that during spring and summer western juniper habitat had the largest estimated number of territorial males for two years. Juniper and ponderosa

Table 3. Provisional use of juniper trees by birds.

		Nesting[1]				Feeding[2]					Cover		Season of Use[3]			
Species	Courting	Ground--stumps, limbs, and logs	Trunk and limbs--natural and excavated holes	Behind loosened bark	On branches and/or in foliage	Ground-fallen berries	Trunk and limb excavations--insects and/or sap	Trunk, limbs, and foliage--gleaning	In tree--berries	Perching and lookout--often pursues prey	Dwarf mistletoe--gleaning and berries	Thermal	Hiding, roosting, and escape	Summer	Winter	Year-long	Source
VULTURES																	
Turkey vulture										X				X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.)
HAWKS and EAGLES																	
Goshawk										X					X		Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Cooper's hawk										X					X		Gabrielson and Jewett (1940), Gashwiler (1977)
Sharp-shinned hawk										X						X	Anderson et al. (1972), Gashwiler (Notes and Obs.)
Marsh hawk														X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940)
Ferruginous hawk					X											X	Bent (1961), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Red-tailed hawk					X					X						X	Anderson and Anderson (1971), Gashwiler (Notes and Obs.), Jewett (1936), Maser (Notes and Obs.)
Swainson's hawk					X					X				X			Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.), Jewett (1936)
Golden eagle										X						X	Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
FALCONS																	
Prairie falcon										X				X			Anderson and Anderson (1971), Gabrielson and Jewett (1940), Gashwiler (1977)
American kestrel			X							X				X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.) Maser (Notes and Obs.)
Merlin										X					X		Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
GROUSE																	
Sage grouse														X			Anderson et al. (1972), Gashwiler (Notes and Obs.)

Table 3. (continued)

Species	Courting	Nesting [1]: Ground--stumps, limbs, and logs	Nesting [1]: Trunk and limbs--natural and excavated holes	Nesting [1]: Behind loosened bark	Nesting [1]: On branches and/or in foliage	Feeding [2]: Ground-fallen berries	Feeding [2]: Trunk and limb excavations--insects and/or sap	Feeding [2]: Trunk, limbs, and foliage--gleaning	Feeding [2]: In tree--berries	Feeding [2]: Perching and lookout--often pursues prey	Feeding [2]: Dwarf mistletoe--gleaning and berries	Cover: Thermal	Cover: Hiding, roosting, and escape	Season of Use [3]: Summer	Season of Use [3]: Winter	Season of Use [3]: Year-long	Source
QUAILS, PARTRIDGES, and PHEASANTS																	
California quail													X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Chukar																X	Anderson and Anderson (1971), Anderson et al. (1972), Pough (1957), Roest (1957)
PIGEONS and DOVES																	
Mourning dove	X				X									X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
OWLS																	
Screech owl			X							X						X	Gabrielson and Jewett (1940), Maser (Notes and Obs.)
Great horned owl					X					X			X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.), Jewett (1936)

Table 3. (continued)

Species	Courting	Nesting[1]: Ground--stumps, limbs, and logs	Nesting[1]: Trunk and limbs--natural and excavated holes	Nesting[1]: Behind loosened bark	Nesting[1]: On branches and/or in foliage	Feeding[2]: Ground-fallen berries	Feeding[2]: Trunk and limb excavations--insects and/or sap	Feeding[2]: Trunk, limbs, and foliage--gleaning	Feeding[2]: In tree--berries	Feeding[2]: Perching and lookout--often pursues prey	Feeding[2]: Dwarf mistletoe--gleaning and berries	Cover: Thermal	Cover: Hiding, roosting, and escape	Season of Use[3]: Summer	Season of Use[3]: Winter	Season of Use[3]: Year-long	Source
GOATSUCKERS																	
Common nighthawk												X	X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.)
HUMMINGBIRDS																	
Rufous hummingbird										X				X			Anderson et al. (1972), Gashwiler (Notes and Obs.)
WOODPECKERS																	
Common flicker	X		X				X									X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)
Lewis' woodpecker			X			X								X			Anderson et al. (1972), Bent (1964a), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Yellow-bellied sapsucker							X							X			Gabrielson and Jewett (1940), Maser (Notes and Obs.)
TYRANT FLYCATCHERS																	
Western kingbird					X					X				X			Anderson and Anderson (1971), Anderson et al. (1972), Bent (1963a), Maser (Notes and Obs.)
Ash-throated flycatcher			X							X				X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.), Maser (Notes and Obs.)
Say's phoebe														X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940)
Dusky flycatcher										X				X			Anderson and Anderson (1971), Anderson et al. (1972), Bent (1963a), Gabrielson and Jewett (1940)
Gray flycatcher	X				X					X			X	X			Anderson et al. (1972), Bertrand and Scott (1971), Gashwiler (1977, Notes and Obs.), Hansen (1956)

Species	Courting	Nesting[1] Ground--stumps, limbs, and logs	Trunk and limbs--natural and excavated holes	Behind loosened bark	On Branches and/or in foliage	Feeding[2] Ground-fallen berries	Trunk and limb excavations--insects and/or sap	Trunk, limbs, and foliage--gleaning	In tree--berries	Perching and lookout--often pursues prey	Dwarf mistletoe--gleaning and berries	Cover Thermal	Hiding, roosting, and escape	Season of Use[3] Summer	Winter	Year-long	Source
SWALLOWS																	
Barn swallow														X			Anderson and Anderson (1971), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Cliff swallow														X			Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Tree swallow														X			Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
JAYS, MAGPIES, and CROWS																	
Steller's jay	X							X	X				X			X	Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Pinyon jay	X				X	X			X				X			X	Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
Black-billed magpie					X			X					X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.), Maser (Notes and Obs.)
Clark's nutcracker	X				X	X			X							X	Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.), Martin et al. (1961)
Common raven					X					X						X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.), Jewett (1936)
Common crow															X		Bent (1964c, part 2), Gabrielson and Jewett (1940), Gashwiler (1977)
CHICKADEES																	
Black-capped chickadee														X			Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
Mountain chickadee			X					X					X			X	Anderson and Anderson (1971), Anderson et al. (1972), Bent (1964c, part 2), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)
VERDIN and BUSHTITS																	
Bushtit								X								X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.), Maser (Notes and Obs.)

Table 3. (continued)

Species	Nesting[1]: Courting	Nesting[1]: Ground--stumps, limbs, and logs	Nesting[1]: Trunk and limbs--natural and excavated holes	Nesting[1]: Behind loosened bark	Nesting[1]: On branches and/or in foliage	Feeding[2]: Ground-fallen berries	Feeding[2]: Trunk and limb excavations--insects and/or sap	Feeding[2]: Trunk, limbs, and foliage--gleaning	Feeding[2]: In tree--berries	Feeding[2]: Perching and lookout--often pursues prey	Feeding[2]: Dwarf mistletoe--gleaning and berries	Cover: Thermal	Cover: Hiding, roosting, and escape	Season of Use[3]: Summer	Season of Use[3]: Winter	Season of Use[3]: Year-long	Source
NUTHATCHES																	
Red-breasted nuthatch								X					X			X	Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
Pygmy nuthatch	X							X					X			X	Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
CREEPERS																	
Brown creeper								X						X			Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
WRENS																	
Rock wren										X				X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.)
MOCKINGBIRDS and THRASHERS																	
Sage thrasher	X									X				X			Bent (1964b), Gashwiler (1977, Notes and Obs.)
THRUSHES, SOLITAIRES, and BLUEBIRDS																	
American robin	X				X	X			X		X	X	X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiller (1977, Notes and Obs.), Maser (Notes and Obs.)
Townsend's solitaire	X					X			X	X		X	X			X	Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)
Hermit thrush														X			Anderson et al. (1972), Gashwiler (1977, Notes and Obs.)
Western bluebird	X		X						X		X		X			X	Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.), Maser (Notes and Obs.)
Mountain bluebird	X		X						X	X	X		X			X	Bertrand and Scott (1971), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)

Species		Nesting [1]				Feeding [2]						Cover		Season of Use [3]			Source
	Courting	Ground--stumps, limbs, and logs	Trunk and limbs--natural and excavated holes	Behind loosened bark	On branches and/or in foliage	Ground-fallen berries	Trunk and limb excavations--insects and/or sap	Trunk, limbs, and foliage--gleaning	In tree--berries	Perching and lookout--often pursues prey	Dwarf mistletoe--gleaning and berries	Thermal	Hiding, roosting, and escape	Summer	Winter	Year-long	
GNATCATCHERS and KINGLETS																	
Ruby-crowned kinglet								X					X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
WAXWINGS																	
Bohemian waxwing									X		X		X		X		Bertrand and Scott (1971), Gashwiler (1977, Notes and Obs.)
Cedar waxwing	X								X		X		X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
SHRIKES																	
Northern shrike	X									X						X	Bertrand and Scott (1971), Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
Loggerhead shrike	X				X					X				X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
STARLINGS																	
Starling									X							X	Gashwiler (Notes and Obs.)
WOOD WARBLERS																	
Orange-crowned warbler														X			Anderson and Anderson (1971), Gabrielson and Jewett (1940)
Yellow-rumped warbler								X					X	X			Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
Townsend's warbler								X					X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
Black-throated gray warbler	X							X					X	X			Bent (1963b, part 1), Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)

Table 3. (continued)

Species	Courting	Nesting [1]: Ground--stumps, limbs, and logs	Nesting [1]: Trunk and limbs--natural and excavated holes	Nesting [1]: Behind loosened bark	Nesting [1]: On branches and/or in foliage	Feeding [2]: Ground-fallen berries	Feeding [2]: Trunk and limb excavations--insects and/or sap	Feeding [2]: Trunk, limbs, and foliage--gleaning	Feeding [2]: In tree--berries	Feeding [2]: Perching and lookout--often pursues prey	Feeding [2]: Dwarf mistletoe--gleaning and berries	Cover: Thermal	Cover: Hiding, roosting, and escape	Season of Use [3]: Summer	Season of Use [3]: Winter	Season of Use [3]: Year-long	Source
Wilson's warbler								X					X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.)
BLACKBIRDS and ORIOLES																	
Western meadowlark	X												X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.)
Brewer's blackbird	X				X				X				X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977), Notes and Obs.), Maser (Notes and Obs.)
Red-winged blackbird														X			Anderson et al. (1971)
Brown-headed cowbird	X												X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.)
Northern oriole	X											X		X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)
TANAGERS																	
Western tanager					X								X	X			Anderson and Anderson (1971), Gashwiler (Notes and Obs.), Maser (Notes and Obs.)
GROSBEAKS, FINCHES, SPARROWS, and BUNTINGS																	
Evening grosbeak						X			X				X		X		Bent (1968a, part 1), Gashwiler (1977, Notes and Obs.), Martin et al. (1961), Maser (Notes and Obs.)
Lazuli bunting	X													X			Anderson and Anderson (1971), Anderson et al. (1972), Gabrielson and Jewett (1940)
Purple finch	X				X					X			X	X			Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.), Hansen (1956)
Cassin's finch	X				X					X			X			X	Gabrielson and Jewett (1940), Gashwiler (1977, Notes and Obs.)
House finch	X				X			X				X	X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)

Species	Courting	Nesting [1]: Ground--stumps, limbs, and logs	Nesting [1]: Trunk and limbs--natural and excavated holes	Nesting [1]: Behind loosened bark	Feeding [2]: On branches and/or in foliage	Feeding [2]: Ground-fallen berries	Feeding [2]: Trunk and limb excavations--insects and/or sap	Feeding [2]: Trunk, limbs, and foliage--gleaning	Feeding [2]: In tree--berries	Feeding [2]: Perching and lookout--often pursues prey	Feeding [2]: Dwarf mistletoe--gleaning and berries	Cover: Thermal	Cover: Hiding, roosting, and escape	Season of Use [3]: Summer	Season of Use [3]: Winter	Season of Use [3]: Year-long	Source
Green-tailed towhee	X									X				X			Anderson and Anderson (1971), Bertrand and Scott (1971), Gashwiler (1977, Notes and Obs.)
Rufous-sided towhee													X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (Notes and Obs.)
Vesper sparrow														X			Bent (1968b, part 2), Gashwiler (Notes and Obs.)
Black-throated sparrow														X			Bertrand and Scott (1971)
Lark sparrow														X			Anderson and Anderson (1971), Anderson et al. (1972), Bertrand and Scott (1971), Gabrielson and Jewett (1940)
Dark-eyed junco	X							X		X		X	X			X	Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.), Maser (Notes and Obs.)
Chipping sparrow	X				X					X			X	X			Anderson and Anderson (1971), Anderson et al. (1972), Bent (1968b, part 2), Gashwiler (1977, Notes and Obs.)
Brewer's sparrow	X												X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.)
White-crowned sparrow	X												X	X			Anderson and Anderson (1971), Anderson et al. (1972), Gashwiler (1977, Notes and Obs.)
Lincoln's sparrow														X			Gashwiler (Notes and Obs.)
Song sparrow														X			Gabrielson and Jewett (1940), Gashwiler (Notes and Obs.), Martin et al. (1961)
Total - 83	29		8		19	6	2	14	12	29	5	6	34	48	6	29	

1 Discussion in text is based upon data for 27 species.

2 Discussion in text is based upon data for 54 species.

Table 4. Provisional use of juniper trees by mammals.

Species	Reproduction: Ground--stumps and logs	Reproduction: In hollow trunks and limbs	Reproduction: In cavities excavated by birds	Reproduction: On limbs and in foliage	Feeding: Ground--fallen berries	Feeding: Trunks and limbs--gleaning	Feeding: Foliage--eaten	Feeding: In tree--berries	Cover Tree: Thermal	Cover Tree: Hiding	Cover Logs: Thermal	Cover Logs: Hiding	Observ. Post: Logs and stumps	Observ. Post: Trees	Season of Use: Summer	Season of Use: Winter	Season of Use: Year-long	Source
BATS																		
Little brown myotis		X	X						X	X					X	?		Maser (Notes and Obs.)
California myotis		X	X						X	X					X	?		Maser (Notes and Obs.)
Big-eared myotis		X	X						X	X					X	?		Maser (Notes and Obs.)
Silver-haired bat		X	X						X	X					X	?		Maser (Notes and Obs.)
Big brown bat		X	X						X	X					X	?		Maser (Notes and Obs.)
Hoary bat [1]				?					X	X					X			Bailey (1936)
RABBITS and HARES																		
Mountain cottontail	X						X		X	X	X	X					X	Maser (Notes and Obs.)
Black-tailed jackrabbit							X		X	X							X	Orr (1940)
RODENTS																		
Mantled ground squirrel [2]	X				X						X	X	X		X			Kindschy (1976), Maser (Notes and Obs.)

Species	Reproduction: Ground--stumps and logs	Reproduction: In hollow trunks and limbs	Reproduction: In cavities excavated by birds	Reproduction: On limbs and in foliage	Feeding: Ground--fallen berries	Feeding: Trunks and limbs--gleaning	Feeding: Foliage--eaten	Feeding: In tree--berries	Cover Tree: Thermal	Cover Tree: Hiding	Cover Logs: Thermal	Cover Logs: Hiding	Observ. Post: Logs and stumps	Observ. Post: Trees	Season of Use: Summer	Season of Use: Winter	Season of Use: Year-long	Source
Townsend ground squirrel [2]												X	X		X			Gashwiler (Notes and Obs.)
Yellow pine chipmunk [2]	X	X	X		X	X		X	X	X	X	X	X	X	X			Johnson (1943), Kindschy (1976), Maser (Notes and Obs.)
Deer mouse	X	X	X		X			X	X	X	X	X					X	Maser (Notes and Obs.)
Pinyon mouse [3]	?	?	?						?	?	?	?					?	Baker and Frischknecht (1973), Gashwiler (Notes and Obs.)
Dusky-footed woodrat	X	X	X	X			X		X	X	X	X					X	Hammer and Maser (1973)
Bushy-tailed woodrat	X	X	X				X		X	X	X	X					X	Hammer and Maser (1973), Maser (Notes and Obs.)
Porcupine		?					X			X							X	Gashwiler (Notes and Obs.)
CARNIVORES																		
Coyote					X				X								X	Hammer (1973), Maser (Notes and Obs.), Shaver (1976)
Long-tailed weasel	X	X	X								X	X					X	Maser (Notes and Obs.)
Spotted skunk	X										X	X					X	Maser (Notes and Obs.)
Bobcat									X	?							X	Maser (Notes and Obs.)
EVEN-TOED HOOFED MAMMALS																		
Elk							X									X		Leckenby (1976)
Mule deer [4]							X		X	X		X				X	X	Dixon (1934), Leckenby and Adams (1976), Sounder and Mowat (1958)
Pronghorn									X	X								Leckenby (1976), Dealy (1977)
Total - 23	8	10	10	1	4	1	7	2	16	15	8	10	3	1	9	2	11	

1 Probably during migration only.
2 These squirrels are listed as active above ground only during the summer but are in fact year-long residents, hibernating underground during the winter.
3 Although these mice were caught in the juniper in the Horse Ridge Research Natural Area near Bend, Deschutes Co., we do not know how they use the juniper.
4 Some deer are resident in the juniper community, but most utilized it as winter range.

pine habitats were dominant on the third year. Western juniper habitat also had the greatest number of territorial species each year. Winter censusing indicated that juniper had the greatest population for two years and was second in the third year. The value of the western juniper habitat for wintering birds was also noted by Gabrielson and Jewett (1940). They wrote: "In good berry years in the extensive juniper forests near Redmond [Oregon], the robins gather in great winter roosts that in the evening look like huge swarms of bees as the birds swirl over the treetops in the twilight before settling down for the night. It is one of the real winter bird sights of eastern Oregon, and it is worth a trip to that section to watch the great numbers of birds entering and leaving the roost. In February or early March, these roosts begin to break up as the arrival of birds from farther south swell the robin population."

Number of species in the western juniper habitat: The provisional list of birds includes 83 species (Table 3). Of these, 48 are summer residents, 6 are winter residents, and 29 were year-long residents (Table 3). The list includes only those birds definitely identified with the western juniper habitat, but some of these birds, like the marsh hawk, are no doubt visitors. As more data become available, this preliminary list will probably change.

Courting: Juniper trees served as perching and singing sites for territory establishment and maintenance, courtship, and mating. The spike tops also function as a fine drumming site for the common flicker. Some of the birds, such as the mountain bluebird, spend hours in the top of a juniper keeping a close lookout over its mate as she lays eggs, incubates, and broods the young.

Nesting: Structurally western juniper appears to be an ideal tree for bird nesting (see Table 3). It has dense foliage, horizontal forks, and many little tufts of twigs on horizontal or slightly angled limbs (Fig. 5). Old decadent junipers are often hollow and supply natural cavities suitable for nesting and roosting. Natural holes also develop at limb sites. In addition, entrance holes to cavities and entire cavities are constructed by flickers. These nest-sites are later used by secondary cavity nesters such as the mountain bluebird, mountain chickadee, and others. There always seems to be more cavity nesters in forests than suitable sites (Jackman 1974); in western juniper many birds settle for marginal sites thereby increasing mortality. Juniper furnishes a variety of nest materials. The finer twigs and coarse bark are used in the outer part and finely shredded inner bark is utilized to make a smooth, soft lining for nest cups.

Nesting sites have been identified and documented, but references to trees in general; specific references to western juniper are sparse. Twenty-seven bird species are known to nest in western juniper: 30% in natural and excavated cavities and 70% in open nests on branches

Figure 5.--Mourning dove, Cabin Lake, Lake County, Oregon. The structure of western juniper trees is well suited to nesting by mourning doves. Horizontal limbs and forks afford good sites for their loosely constructed nests (U.S. Fish and Wildlife Service photograph by J. S. Gashwiler).

and/or in foliage. This is 10% fewer cavity nesters than was reported by Jackman (1974) for other coniferous forest habitats.

Feeding: Western juniper trees appear to be populated by many species of insects. Insect production is one of the habitat's important contributions to the bird community because of the positive correlation between food availability and time of nesting (Davis 1933). Insects provide food for nestlings and adults. Succulent spring and early summer larvae provide moisture; this source of moisture may account for the presence of robins in some of the arid juniper habitats. Adult and larval insects are harvested by birds gleaning (searching) the trunk, limbs, and foliage. Twenty-six percent of the 54 species found in the

feeding portion of Table 3 are considered to be gleaners. On the other hand, 4% of the 54 species feed by excavating trunks and limbs for insect larvae and sap (Table 3, Fig. 6).

Figure 6.--Sapsucker holes in western juniper, Horse Ridge Research Natural Area, Deschutes County, Oregon (photograph by C. Maser).

Juniper berries are an important source of food for wintering birds (Martin et al. 1961). Thirty-two percent of the 54 species in the feeding portion of Table 3 feed on western juniper berries. Birds eat berries off of the tree and also harvest ripe ones which have fallen to the ground. The hard nutlet(s) within the berries often pass unharmed through the birds alimentary tracts and are distributed widely.

Birds use western juniper trees as lookout stations for hunting and for protection. Some birds, such as the flycatchers, have developed this aerial method (perching--swooping) of feeding to a high state of perfection. Many birds, especially the raptors, have favorite perching trees,

generally where they have a wide overlook, and can be observed frequently using the same perch. Fifty-five percent of the 54 species in the "feeding" portion of Table 3 are in the perching and lookout category.

Juniper dwarf mistletoe, indigenous to western juniper, produces a small pearl-like berry eaten by waxwings, robins, and other species in fall and winter. Birds may also glean insects from mistletoe clumps. Nine percent of the 54 species obtain food from mistletoe (Table 3).

Cover: Western juniper habitat is influenced by the presence of the trees in that they dampen wind velocity. Wind velocity in juniper habitat is often sufficiently abated so that birds will remain active when nearby sagebrush areas exhibit reduced bird activity. This is especially important in winter when the day length is short, energy requirements are high, and birds need to forage steadily to survive. The decreased wind velocity also lowers the chill factor thus decreasing the birds' food requirements. The interior of tree crowns also provides important thermal cover during hot summer days.

Mammals

Reproduction: Of the 23 species of Oregon mammals that utilize western juniper, only 7 depend upon it as sites for rearing young--5 species of bats and 2 species of woodrats (Table 4). The bats, with the possible exception of the silver-haired bat, are known to form nursery colonies in hollow trees (Barbour and Davis 1969). Although silver-haired bats probably roost singly, they may also bring forth their young in hollow trunks and limbs. (Albeit there are no data available for Oregon bats, there is a strong possibility that some of the species listed in Table 4 may also hibernate in hollow junipers.) Bushy-tailed and dusky-footed woodrats nest and rear their young in hollow juniper trees and hollow logs (Figs. 7 & 8). In the absence of suitable cliffs, rimrocks, or talus, bushy-tailed woodrats are dependent upon hollow juniper trees and/or logs as nesting sites, but dusky-footed woodrats also construct sturdy nests of sticks on juniper limbs (Fig. 9). Where the two species occur together, the dusky-foots out-compete the bushy-tails for nesting sites in juniper (Hammer and Maser 1973).

Feeding: Woodrats are dependent upon juniper foliage as food (Fig. 10). In fact, dusky-footed woodrats in south-central Oregon (Klamath and Lake Counties) are predominantly dependent upon juniper foliage as food. They occasionally cut all the foliage off of a tree, killing it (Hammer and Maser 1973). Porcupines also use juniper twigs and foliage for food, especially in winter. Mountain cottontails and black-tailed jackrabbits feed on juniper foliage to some extent as do mule deer and elk (Table 4).

Deer mice and coyotes eat juniper berries during the fall and winter. Juniper seeds opened by deer mice (Fig. 11) can be found wherever there is a berry crop and coyote droppings composed solely of juniper berries are frequently encountered. Yellow pine chipmunks and mantled ground

Figure 7.--Nest of a bushy-tailed woodrat in a hollow, decadent western juniper, 9.6 kilometers south of Prineville, Crook County, Oregon. Note sticks and food-twig at entrance to nest cavity (photograph by C. Maser).

Figure 8.--Hollow western juniper log inhabited by a bushy-tailed woodrat, 9.6 kilometers south of Prineville, Crook County, Oregon (photograph by C. Maser).

Figure 9.--Nest of a dusky-footed woodrat in a western juniper tree, 2.4 kilometers southwest of Bonanza, Klamath County, Oregon (photograph by C. Maser).

Figure 10.--Twigs of western juniper cut and stored by a bushy-tailed woodrat, Connley Caves, Lake County, Oregon (photograph by C. Maser).

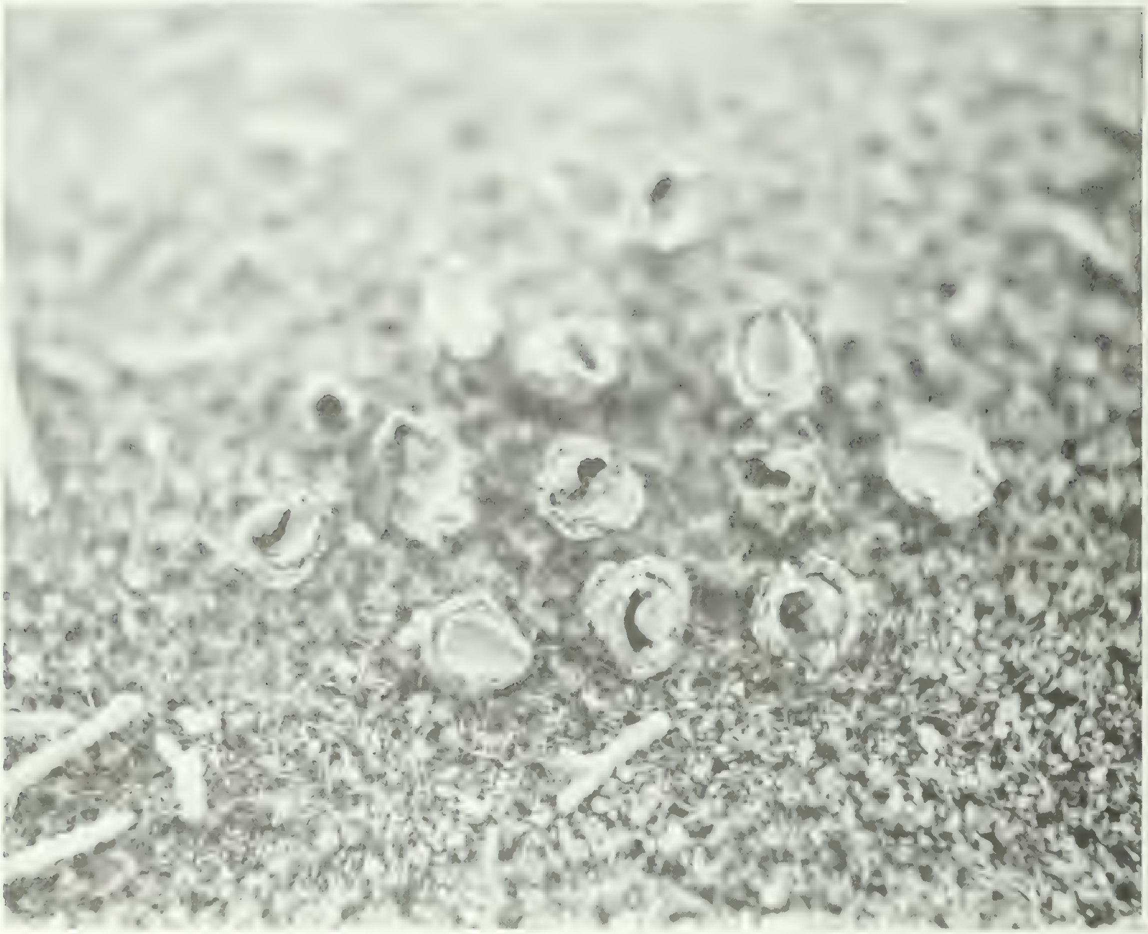

Figure 11.--Nutlets of western juniper opened by deer mice, Connley Caves, Lake County, Oregon (photograph by C. Maser).

squirrels also consume juniper berries (Kindschy 1976).

Cover: Junipers, with full-length crowns, provide critical hiding and thermal cover protection for non-climbing animals. Hollow trees and hollow logs are important resting places for several species, especially bats and woodrats. In this instance, the emphasis is on hiding cover which provides security.

Shade during hot weather is important to diurnal species. Shade from trunks, crowns, and downed material is also used. During winter months, on the other hand, large, full-crowned junipers often keep the ground beneath their crowns snow-free by snow interception, and reduce heat reradiation from the ground and animals to the sky. Such areas are utilized by deer, coyotes, bobcats, and other animals as places to sun themselves, helping to conserve vital energy required to maintain body heat during inclement weather.

ENHANCEMENT OF JUNIPER COMMUNITIES FOR WILDLIFE

In spite of our meager knowledge of the juniper communities as a whole, there are several ways in which they can be enhanced as wildlife habitat; these are discussed in general terms.

Water

Since many, or most, juniper areas are situated away from a source of free water, the establishment of water impoundments would benefit wildlife. Although permanent water would probably be the most beneficial, a supply of water during the reproductive season would add substantially to the potential importance of an area.

Careful location of water impoundments is important for maximum utilization by wildlife. The areas which receive the heaviest animal use are mature and decadent stands of juniper, cliffs within 0.4 to 0.8 kilometers of permanent water, and along ecotones between plant communities (Maser et al. 1978, Thomas et al. 1978a, Thomas et al. 1978b).

The design of a water impoundment determines which species of animal can use it; proper designing, therefore, is essential. If a trough is too high, small animals cannot reach the water. Round troughs and guzzlers do not offer enough surface area for bats, swallows, and nighthawks--which drink on the wing. Deep troughs without ramps or piles of rocks within are not safe for birds or small mammals.

Bird boxes

Since the density of cavity nesters is limited by the number of available cavities (Jackman 1974), the placement of nesting boxes in the western juniper habitat would seem to be a good method of supplementing the natural and excavated cavities for nesting and roosting, thus increasing the potential bird population, particularly in younger juniper stands.

Boxes placed in the proximity of water would probably be most productive.

Development of openings

When openings (chainings, cuttings, burnings, etc.) are created in a juniper community, the following should be considered: (1) Openings should be irregular in shape to maximize the edge effect. (2) Juniper trees should be left in stringers to form travel lanes and in islands to create habitat diversity. (3) Trees being used by cavity nesters, hollow trees and logs, should be protected and left for hiding cover and reproductive habitat whenever possible. (4) Debris piles should be of a size, shape, depth, and placement which allows maximum use by wildlife. (5) A diversity of food and cover, such as forbs, grasses, and shrubs, should be seeded within an opening or within the juniper community where such plants are lacking. (6) Perching and lookout trees should be left at strategic places for the use of hawks, owls, flycatchers, and other species (see Table 3).

RESEARCH NEEDS

There is much to be learned about the interrelationships of wildlife and juniper in Oregon. (1) Resident and transient wildlife in juniper communities need to be inventoried. (2) Wildlife use of trees individually and of communities as a whole needs to be determined. (3) Along with basic wildlife inventories, we need to know how and why wildlife respond to different, undisturbed western juniper communities (*sensu stricto*) so that we may know how to interpret cause and effect relationships and predict these with respect to habitat manipulation. (4) Effects of manipulation of juniper communities on wildlife need to be specifically studied. The first three research needs are self-explanatory, but the fourth (effects of manipulation) requires clarification.

Type of manipulation

Fire: Some studies of the effects of fire on wildlife have been conducted (Chew et al. 1959, Cook 1959, Eastman 1976, Howard et al. 1959, McCulloch 1969, and others), but we found nothing specific to western juniper communities in Oregon. There is, however, a metalic wood-boring beetle (*Melenophila miranda* LeC., Buprestidae) that is so adapted to fire in juniper that females normally lay their eggs on trees that have been just burned. As a tree cools, the female lays eggs near the ground in the wood which sometimes is so hot that her feet are burned off (Beer 1976). Such a relationship points to a long history of fire within the juniper community and to the naturalness of fire as a management tool.

Chaining: Baker and Frischknecht (1973) studied the effect of chaining on small mammals in juniper rangeland in Utah, but little or nothing has been done in Oregon.

Cutting: Although we found no data on the effects of felling juniper

vs chaining, one of us (CM) has looked at cuttings and found them to have excellent potential for creating diversity of wildlife habitats.

Size of manipulation

We need to examine different sizes of openings--cuttings, chainings, and burns--to determine the minimum and the maximum sizes needed to accommodate various types of wildlife and their uses of the areas.

Debris piles

Size, depth, shape, and placement of debris piles should be studied to determine which type allows maximum use by wildlife over time.

Cost-benefit analysis of juniper manipulation

There have been some studies of the multiple-use benefits of pinyon-juniper management, e.g., Clary (1975) in Arizona and Jensen (1972) in Nevada. However, while we need to address ourselves to the multiple-use benefits of juniper management, we also have to consider the cost-benefits of such management, including non-game wildlife.

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ppendix 1. Common and scientific names of plants and animals referred to in text.

Family	Common Name	Scientific Name
LANTS [1]		
uniper (Cupressaceae)	Western juniper	Juniperus occidentalis
ines (Pinaceae)	Lodgepole pine Ponderosa pine	Pinus contorta Pinus ponderosa
istletoe (Loranthaceae)	Juniper dwarf mistletoe	Phoradendron juniperinum
agebrush (Compositae)	Big sagebrush	Artemisia tridentata
IRDS [2]		
ultures (Cathartidae)	Turkey vulture	Cathartes aura
awks and eagles (Accipitridae)	Goshawk Cooper's hawk Sharp-shinned hawk Marsh hawk Ferruginous hawk Red-tailed hawk Swainson's hawk Golden eagle	Accipiter gentilis Accipiter cooperii Accipiter striatus Circus cyaneus Buteo regalis Buteo jamaicensis Buteo swainsoni Aquila chrysaetos
lcons (Falconidae)	Prairie falcon Merlin American kestrel	Falco mexicanus Falco columbarius Falco sparverius

Grouse (Tetraonidae)	Sage grouse	Centrocercus urophasianu
Quail, partridges, and pheasants (Phasianidae)	California quail Chukar	Lophortyx californicus Alectoris chukar
Pigeons and doves (Columbidae)	Mourning dove	Zenaida macroura
Owls (Tytonidae)	Screech owl Great horned owl	Otus asio Bubo virginianus
Goatsuckers (Caprimulgidae)	Common nighthawk	Chordeiles minor
Hummingbirds (Trochilidae)	Rufous hummingbird	Selasphorus rufus
Woodpeckers (Picidae)	Common flicker Lewis' woodpecker Yellow-bellied sapsucker	Colaptes auratus Asyndesmus lewis Sphyrapicus varius
Tyrant flycatchers (Tyrannidae)	Western kingbird Ash-throated flycatcher Say's phoebe Dusky flycatcher Gray flycatcher	Tyrannus verticalis Myiarchus cinerascens Sayornis saya Empidonax oberholseri Empidonax wrightii
Swallows (Hirundinidae)	Barn swallow Cliff swallow Tree swallow	Hirundo rustica Petrochelidon pyrrhonota Iridoprocne bicolor
Jays, magpies, and crows (Corvidae)	Steller's jay Pinyon jay Black-billed magpie Clark's nutcracker Common raven	Cyanocitta stelleri Gymnorhinus cyanocephalus Pica pica Nucifraga columbiana Corvus corax

	Common crow	Corvus brachyrhynchos
hickadees and bushtits (Paridae)	Black-capped chickadee Mountain chickadee Bushtit	Parus atricapillus Parus gambeli Psaltriparus minimus
uthatches (Sittidae)	Red-breasted nuthatch Pygmy nuthatch	Sitta canadensis Sitta pygmaea
reepers (Certhiidae)	Brown creeper	Certhia familiaris
rens (Troglodytidae)	Rock wren	Salpinctes obsoletus
ockingbirds and hrashers (Mimidae)	Sage thrasher	Oreoscoptes montanus
hrushes, solitaires, nd bluebirds (Turdidae)	American robin Townsend's solitaire Hermit thrush Western bluebird Mountain bluebird	Turdus migratorius Myadestes townsendi Catharus guttatus Sialia mexicana Sialia currucoides
natcatchers and inglets (Sylviidae)	Ruby-crowned kinglet	Regulus calendula
axwings (Bombycillidae)	Bohemian waxwing Cedar waxwing	Bombycilla garrulus Bombycilla cedrorum
hrikes (Laniidae)	Northern shrike Loggerhead shrike	Lanius excubitor Lanius ludovicianus
tarlings (Sturnidae)	Starling	Sturnus vulgaris

Wood warblers (Parulidae)	Orange-crowned warbler Yellow-rumped warbler Townsend's warbler Black-throated gray warbler Wilson's warbler	Vermivora celata Dendroica coronata Dendroica townsendi Dendroica nigrescens Wilsonia pusilla
Blackbirds and orioles (Icteridae)	Western meadowlark Red-winged blackbird Brewer's blackbird Brown-headed cowbird Northern oriole	Sturnella neglecta Agelaius phoeniceus Euphagus cyanocephalus Molothrus ater Icterus galbula
Tanagers (Thraupidae)	Western tanager	Piranga ludoviciana
Grosbeaks, finches, sparrows, and buntings (Fringillidae)	Evening grosbeak Lazuli bunting Purple finch Cassin's finch House finch Green-tailed towhee Rufous-sided towhee Vesper sparrow Lark sparrow Black-throated sparrow Dark-eyed junco Chipping sparrow Brewer's sparrow White-crowned sparrow Lincoln's sparrow Song sparrow	Hesperiphona vespertina Passerina amoena Carpodacus purpureus Carpodacus cassinii Carpodacus mexicanus Chlorura chlorura Pipilo erythrophthalmus Pooecetes gramineus Chondestes grammacus Amphispiza bilineata Junco hyemalis Spizella passerina Spizella breweri Zonotrichia leucophrys Melospiza lincolnii Melospiza melodia
MAMMALS [3]		
Bats (Vesperlilionidae)	Little brown myotis	Myotis lucifugus

	Long-eared myotis California myotis Silver-haired bat Big brown bat Hoary bat	Myotis evotis Myotis californicus Lasionycteris noctivagans Eptesicus fuscus Lasiurus cinereus
Rabbits and hares (Leporidae)	Mountain cottontail Black-tailed jackrabbit	Sylvilagus nuttalli Lepus californicus
Chipmunks and ground squirrels (Sciuridae)	Yellow pine chipmunk Townsend ground squirrel Mantled ground squirrel	Eutamias amoenus Spermophilus townsendi Spermophilus lateralis
Native mice and rats (Cricetidae)	Deer mouse Pinyon mouse Dusky-footed woodrat Bushy-tailed woodrat	Peromyscus maniculatus Peromyscus truei Neotoma fucipes Neotoma cinerea
New world porcupines (Erethizontidae)	Porcupine	Erethizon dorsatum
Dogs (Canidae)	Coyote	Canis latrans
Weasels and skunks (Mustelidae)	Long-tailed weasel Spotted skunk	Mustela frenata Spilogale putorius
Cats (Felidae)	Bobcat	Lynx rufus
Elk and deer (Cervidae)	Elk Mule deer	Cervus canadensis Odocoileus hemionus
Pronghorn (Antilocapridae)	Pronghorn	Antilocapra americana

Appendix footnotes

1 Plant nomenclature follows Hitchcock and Cronquist (1974).

2 Bird nomenclature follows Robins et al. (1966) except where they are superseded by the American Ornithologists' Union (1973).

3 Mammal nomenclature follows Hall and Kelson (1959) except where they are superseded by Burt and Grossenheider (1964).

COMPETITIVE MOISTURE CONSUMPTION BY THE WESTERN JUNIPER (JUNIPERUS OCCIDENTALIS)

Darwin J. Jeppesen, Soil Scientist
Bureau of Land Management
Prineville, Oregon

ABSTRACT

Western junipers are not only strong competition for soil moisture, but appear to utilize much of the winter-accumulated soil moisture before herbaceous plant competition for soil moisture begins.

Keywords: Western juniper, soil moisture, transpiration, wilting range, winter dormancy.

INTRODUCTION

The invasion of the western juniper in arid lands in eastern Oregon has become a matter of grave concern by land resource managers during the last decade. The invasion of western juniper in the west is attributed to man's control of its natural enemy, fire, and the removal of understory fire fuels by grazing practices (Burkhardt and Tisdale 1976). As western juniper plant communities increase in density, they develop a dominance in soil moisture consumption that hampers all other plants' efforts to re-establish themselves. This paper will attempt to show that western juniper utilizes winter soil moisture while most other plant species are dormant and that juniper competes vigorously with other species throughout the year to maintain its edge on overall moisture consumption.

LITERATURE REVIEW

Few soil moisture pattern studies in juniper and juniper-cleared areas have been made. Skau (1964) found in Arizona that clearing alligator juniper (*Juniperus deppeana*) and Utah juniper (*Juniperus osteosperma*) on the Beaver Creek watershed resulted in only 1 to 3 percent moisture increase in cleared juniper areas. He explained that such a small difference may have been due to the accumulation of one to nine times as much ground cover plants on the thinned plots. Forage often increases more than 100 percent by the removal of woody plants (Fanning 1964, Clary 1971, Clary 1974).

Studies by Gifford and Shaw (1973) on cleared pinyon-juniper sites in southwestern and southeastern Utah indicate that greater moisture accumulation occurred under a debris-in-place treatment as compared to woodland controls during the first 6 months of each year at Milford, and regardless of season at Blanding. Woodland soils had the least soil moisture throughout most of the year. Most moisture flux took place in the upper (24 to 36 inches) of the soil profile, with only minor changes occurring at greater depths.

STUDY AREA AND METHODS

The study areas are located about 25 miles southeast of Prineville, Oregon, in the Bear Creek drainage. Bear Creek is a tributary to the Prineville Reservoir, located on the Crooked River in the Deschutes River basin. Soil parent materials are alluvium and surficial aeolian deposits of the John Day Formation (Swanson 1969).

The average rainfall is about 12 inches. Soils are deep, loam, Calcic Haploxerolls of the fine-loamy, mixed, mesic family at Hook Ridge near Fisher Canyon, and at Long Hollow are sandy loam, Cumulic Haploxerolls of the coarse-loamy, mixed, mesic family and loam, Calcic Pachic Argixerolls of the fine-loamy, mixed, mesic family. The soil pH is 7.8 near the surface and 8.6 below 30 inches. Elevation is 4000 feet and frost may occur in any month. Even though suborders and the soil families vary at each site, soil textures are relatively similar to all depths.

Natural vegetation for each site would be similar to a Soil Conservation Service Juniper Rolling Hills range site.

An automatic recording Belfort rain gage was installed in the natural juniper woodland at Hook Ridge and a fiberglass soil moisture-temperature cell was placed 5 feet southeast of the rain gage at a depth of 20 inches. A similar installation was made on the lower end of Bear Creek at 3500 feet elevation, and the fiberglass soil moisture-temperature cell was placed in a pole line corridor. On or near the 15th of each month, the 30-day gain gage charts were changed and the electrical resistance of the fiberglass cells was read for soil temperature and moisture with a soil moisture-temperature meter MC-300B from Soil Test.

After observing the apparent winter soil moisture loss, we dug a pit 5 feet east of the Hook Ridge rain gage on July 2, 1976. The soil profile was described and additional fiberglass cells were installed at the 6-, 12-, 20- and 30-inch depths. Pits were dug and the soils described at Long Hollow in adjacent thinned and unthinned juniper woodland area. Fiberglass cells were also installed at the 6-, 12-, 20- and 30-inch soil depths. Readings were made after major storms and on or near the 15th of each month.

The juniper in the Long Hollow thinned area were hand-cut with debris left in place in 1973. Terrific native grass plant release was apparent with many herbaceous species more than 2 feet tall. A point transect method of measuring frequency of vegetation in the Long Hollow adjacent sites had been made in the late summer of 1975. A 100-foot tape was laid out between two steel fence posts and point vegetation was recorded at 1-foot intervals. The woodland site had 1 percent understory vegetation, 29 percent litter and 70 percent bare ground. The thinned site had 34 percent vegetation, 59 percent litter and 30 percent bare ground. Hand clippings of vegetation in 1976 indicated 61 pounds dry weight of herbaceous species in the woodland site and 357 pounds in the thinned site.

RESULTS AND DISCUSSION

Winter Soil Moisture

The soil profile at Hook Ridge was moist as a result of heavy fall rains when the fiberglass cell was installed on November 15, 1975. Snow continued through January 7, 1976, but surface ground conditions were frozen and it is felt that little winter moisture reached the 20-inch depth. The available soil moisture at 20 inches, with warmer soil temperatures, was depleted rapidly in the woodland juniper area (fig. 1). In comparison, soil moisture at lower Bear Creek (fig. 2) and High Desert (fig. 3) remained much higher through the winter months. Because of the winter dormancy of the associated vegetative species, low number of total plants and frozen ground near the soil surface, the loss of winter soil moisture at Hook Ridge was attributed to juniper winter transpiration. The soil moisture content at 20 inches went from near field capacity to the wilting range between the 15th of December and the 15th of January. The soil temperature remained between 33 to 39^{o} Fahrenheit during this period.

Summer Soil Moisture

A record 4.4 inches of rain fell in the first 2 weeks of August 1976, one month after the additional soil moisture cells were installed. Greater concentrations of moisture were found in the thinned woodland site at the 6- and 12-inch depth before and after the heavy rains (fig. 4). Woodland sites at the same depths returned to wilting range in October, while soil moisture remained in the 6-inch level thinned site until November, and the site continued to be very moist at the 12-inch level throughout the remainder of the year. Moisture reached the 20-inch level sometime after the August rains and disappeared by the end of November at each site. The 30-inch level showed very little influence from the August storm except at the Long Hollow woodland site, which has the lightest soil texture and thus the lowest water holding capacity of the three sites. The figures indicate a more rapid depletion of moisture in the fall on the juniper woodland site than on the thinned woodland sites

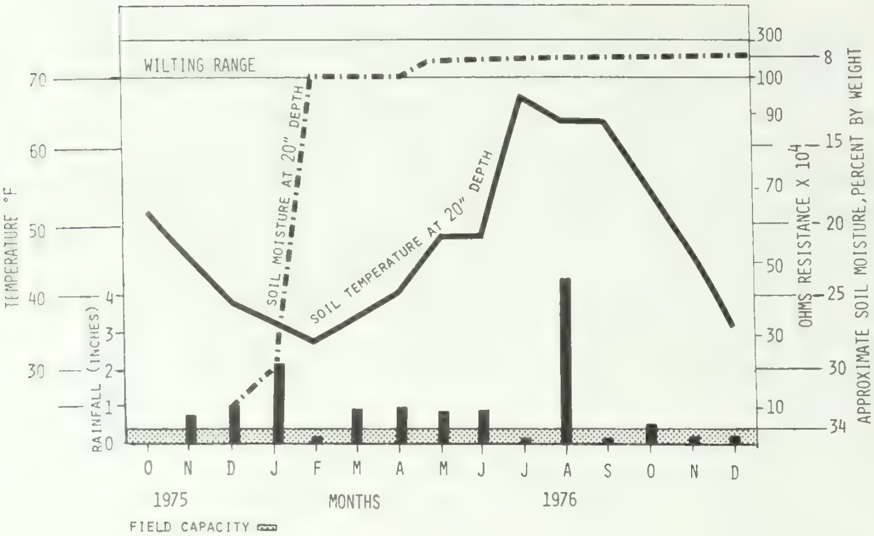

Figure 1.--Rainfall and soil moisture and temperature at the 20-inch depth for the Hook Ridge Study Area, 1975 and 1976. Rainfall is presented as bars for each month. The site has a south aspect with 5 percent slope at 4000-foot elevation.

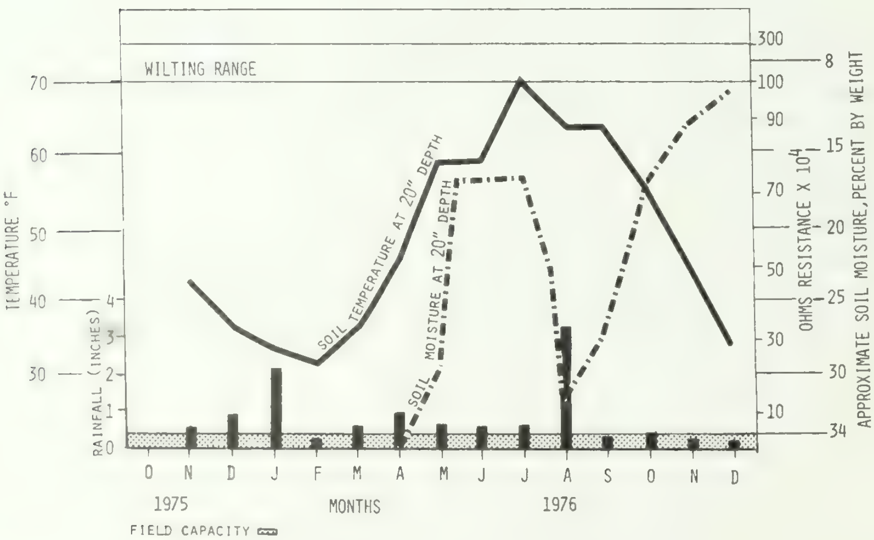

Figure 2.--Rainfall and soil moisture and temperature at the 20-inch depth for Lower Bear Creek Study Area in 1975 and 1976. Rainfall is presented as bars for each month. The site has a southeast aspect with 4 percent slope at 3500-foot elevation.

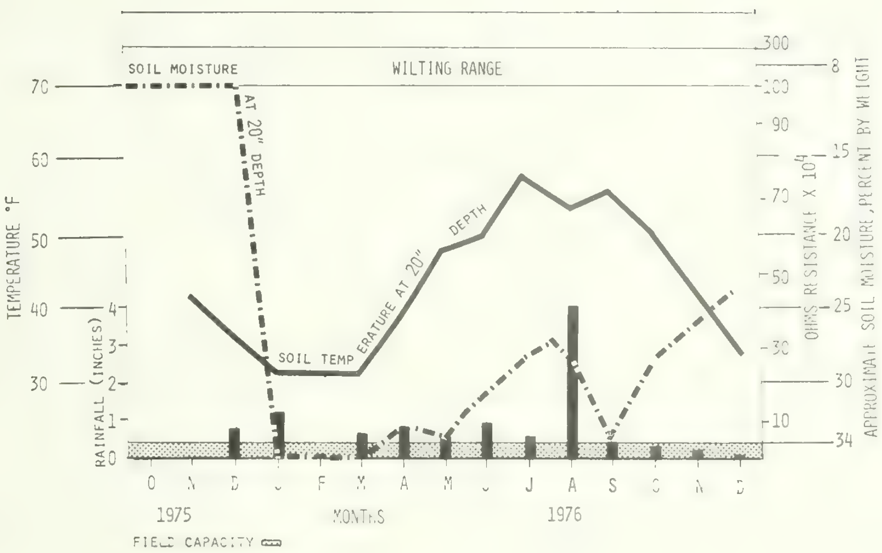

Figure 3.--Rainfall and soil moisture and temperature at the 20-inch depth for the High Desert Study Area (no juniper) in 1975 and 1976. Rainfall is presented as bars for each month. The site has a southeast aspect with a 3 percent slope at 4460-foot elevation.

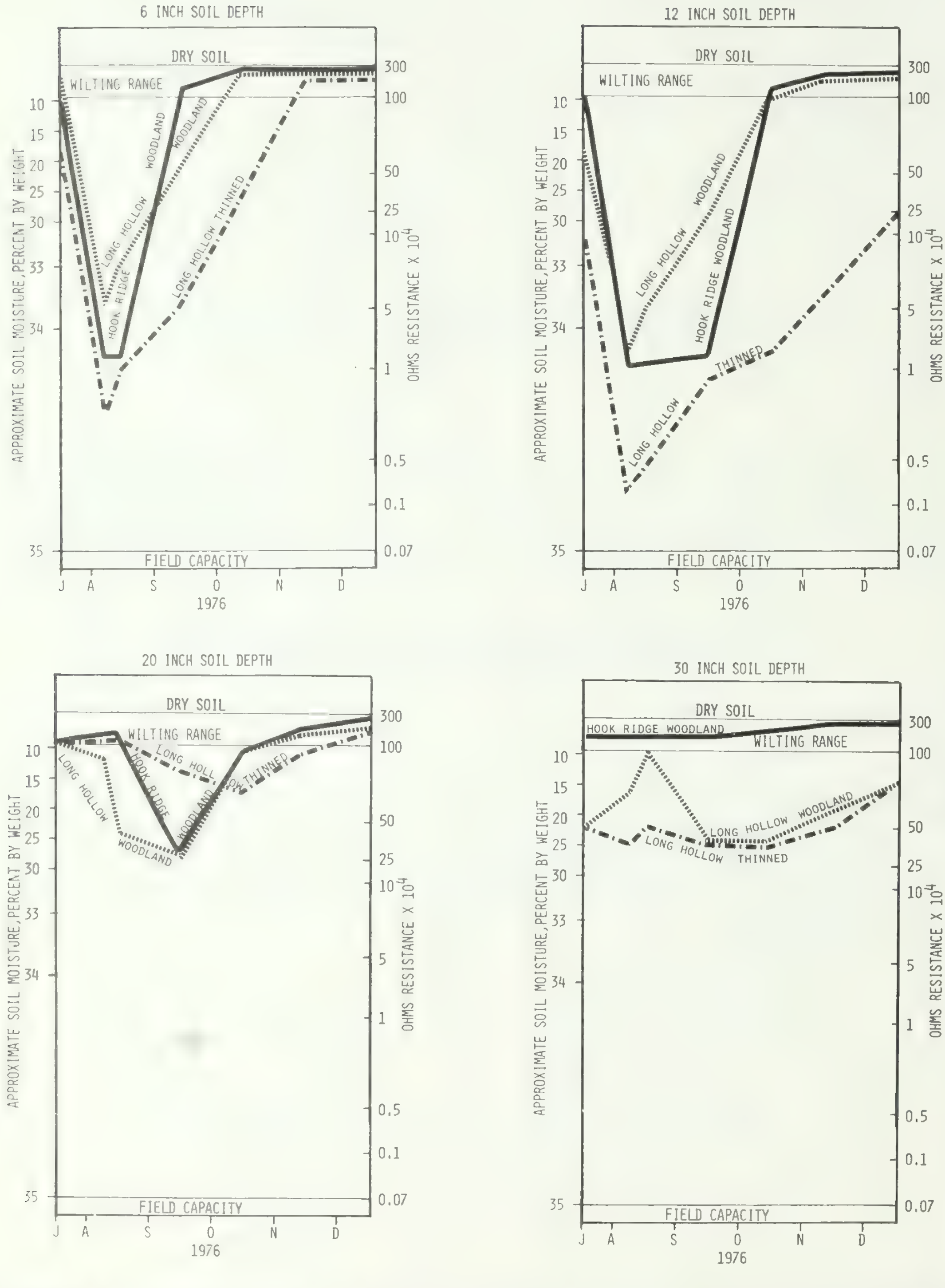

Figure 4.--Comparison of soil moisture content from July through December 1976 for woodland and thinned sites at the 6-, 12-, 20-, and 30-inch depths.

with high native grass plant populations. The data also indicate that most of the moisture flux occurs between the 6- to 20-inch soil depth in the summer.

CONCLUSIONS

There is a strong indication that western juniper uses a great deal of soil moisture for transpiration during the winter months. If subsoils are not frozen, western juniper can apparently use soil moisture rapidly throughout the year. In low rainfall areas where soil moisture storage is light, western juniper utilizes most of the stored soil moisture with its apparent year-around transpiration ability and gains a plant dominance in existing plant communities.

The use of deep soil moisture during winter months by heavy stands of western juniper, while most other species are dormant, will have a considerable effect on most spring and summer plants during most years. This may explain slow understory species re-establishment in juniper woodland areas and lack of plant vigor by most species throughout the season, even under ungrazed conditions.

Additional research should be conducted to establish the validity of the above findings, and to measure the transpiration and evapotranspiration rate for the western juniper for both winter and summer. Research is also needed to determine proper juniper management methods and their ecological effect.

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WEATHER STRESS DIFFERENCE BETWEEN TWO LEVELS OF JUNIPER CANOPY COVER

Larry Bright
Oregon Department Fish and Wildlife
Prineville, Oregon

ABSTRACT

Weather index values and differences between two mule deer winter range situations were obtained by measuring the difference in microclimate between a juniper forest and open shrubland. The cumulative weather stress in the shrubland was 2.2 times more severe than in the juniper forest through the winter period.

Deer observations during the Silver Lake Research Study have documented specific deer use of cover and forage areas dependent upon certain weather conditions. Predominant deer use occurred in juniper stands during weather stress and in open shrublands during less severe conditions.

The presence of thermal protection in juniper stands of 25 percent crown canopy cover was shown by the results of this study. The value of thermal protection to mule deer has been demonstrated during other studies.

The presence of measurable thermal value supports the need for developing proper guidelines for management of juniper stands on deer winter ranges. Thermal values would also benefit livestock wintering in juniper areas.

Keywords: Juniper, deer, thermal cover, weather index.

INTRODUCTION

Habitat improvement projects for mule deer on winter ranges have historically centered on forage development with little regard for cover value either by itself or in conjunction with forage values. The importance of proper size and distribution of forage and cover areas have been well documented (Moen 1973). The value of thermal cover provided by juniper (Juniperus occidentalis Hook.) stands is

thoroughly discussed and related to work by Geiger (1966) describing microclimate changes related to canopy cover. During periods of severe stress, usually characterized by subfreezing temperatures, chilling winds and snow cover, the value of thermal cover is far more important than a wide open expanse of forage. Under these conditions the forage is (1) unavailable under snow most of the time and/or is (2) located in a microclimate that costs the deer more energy to obtain the forage than is received from it in terms of metabolizable energy. Analysis of deer observations during the Silver Lake Research Study documented animal behavior and use patterns in forage and cover areas that prove the need for proper distribution of thermal cover and forage for wintering mule deer (Leckenby, in manuscript).[1]

OBJECTIVE

The objective of this study was to determine the difference in the microclimate between two levels of juniper cover as measured by the weather stress index from two weather stations.

TECHNIQUES

A weather index which simulates relative stress values to mule deer based upon animal physiology was developed by Leckenby and Adams[2] while working on the Silver Lake Research Project. The numerical stress values are developed from functions of percent snow cover, snow depth, total wind, hours recorded in certain temperature ranges and measured precipitation. The techniques used are described (Adams and Leckenby 1972).[3]

Each station was equipped with the following instruments including a standard design instrument shelter:

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[1] Leckenby, D.A. Mule deer occupancy of plant communities on a south-central Oregon winter range. Oregon Dept. Fish and Wildlife. In manuscript.

[2] Leckenby, D.A., and A.W. Adams. A weather severity index for mule deer on a south-central Oregon winter range. Oregon Dept. Fish and Wildlife. In manuscript.

[3] Adams, A.W., and D.A. Leckenby. 1972. Suggestions for the development of a weekly weather index. Oregon State Game Comm. Mimeo.

1. Hygrothermograph
2. Dial-type recording anemometer
3. Precipitation collecting drum
4. Maximum-minimum thermometer in Townsend support
5. Standard maximum-minimum thermometer in Townsend support
6. A Forschner's improved circular milk scale, Model 69 MD

A computer program was written to compute a weekly and cumulative stress index from data obtained at each weather station on a weekly basis.

During the winter of 1974-75, recordings were analyzed from two weather stations located near the Stratton Place on the Fort Rock winter range from November 4, 1974 through June 2, 1975. The more open "shrubland station" has been in operation since 1968-69 and is located on a rabbitbrush flat with less than 5 percent crown canopy cover provided by scattered juniper. The plant community is gray rabbitbrush/squirreltail-cheatgrass (*Chrysothamnus nauseosus* (Pall.) Brit.)/(*Sitanion hystrix* (Nutt.) J.G.Sm.)-(*Bromus tectorum* L.). The other station was placed on a 15 percent south facing slope in a juniper stand of approximately 25 percent crown canopy cover. This community is juniper/big sage (*Artemisia tridentata* Nutt.)/needlegrass (*Stipa* spp.)-squirreltail.

Data collected from the two stations provided sound information from which to determine and measure the difference in microclimates.

RESULTS

The weekly and cumulative index values for each station are plotted on Figures 1 and 2. The zero (0) line is the threshold below which mule deer enter a stress situation, i.e., they start using more energy for maintenance than is being obtained from forage. Index values above the line indicate positive conditions when mule deer can gain body condition and store energy reserves above levels required for maintenance.

The weekly index plotted in Figure 1 illustrates the difference between microclimates in terms of weather stress for each week throughout the winter. Deer use during severe stress situations has been observed to shift heavily to juniper forest stands and away from shrubland browse communities (Leckenby, in manuscript). The main reason is shown in Figure 1 where the thermal stress is more severe in the shrubland compared to the juniper stand. It should be pointed out that there is a rather minimal difference between these two stands in terms of canopy cover (5 and 25 percent) and that proportionally more thermal protection is provided in stands with increased canopy cover.

The difference as illustrated in Figure 1 is not visually dramatic due to the scale of the graph, but is significant in terms of numerical values.

During milder periods, deer use of shrublands increases substantially when they can obtain metabolizable energy at a benefit/cost ratio greater than 1. These periods can be seen on Figure 1 and they also occur on a daily basis when weather allows. As daytime microclimate conditions in shrubland improve to equal that of juniper forest, deer forage use of open areas increases. Deer return to juniper (thermal) protection as the shrubland microclimate approaches the physiological limits to exposure to cooler temperatures.

The cumulative index as shown in Figure 2 illustrates the overall difference in microclimate between the two levels of canopy cover throughout the winter. The shrubland microclimate stress factor was 222 percent more severe than in the juniper forest. A subpopulation of deer which have depended upon a particular juniper stand for thermal cover each winter would suddenly find themselves in a critical, if not fatal, situation if the stand were to be removed in order to improve forage conditions. Under severe stress conditions they could eat all the new forage supplies and still die of undernutrition. The forage could not supply sufficient nutrition to replace additional energy losses to increased stress conditions created by thermal cover removal. Body condition is lost much faster while feeding in open range under severe stress than would be lost while not feeding, but under thermal protection energy can be conserved.

CONCLUSIONS

The difference in microclimate between the shrubland and the juniper forest as shown in Figures 1 and 2 is a strong indication of the relative value of thermal protection to wintering mule deer. Studies of climatic changes as discussed in Moen (1973), Geiger (1966) and Leckenby (in manuscript), and the effects of climatic conditions upon ruminant physiology have revealed sound knowledge for developing guidelines to manage juniper stands and thus maximize thermal protection and use of forage in terms of the most efficient benefit/cost ratio to the deer's energy balance.

LITERATURE CITED

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Figure 1.--Weekly weather index for shrub and juniper cover in the Silver Lake Study area, winter 1974-1975. Below the zero level, deer use more energy than they obtain from forage.

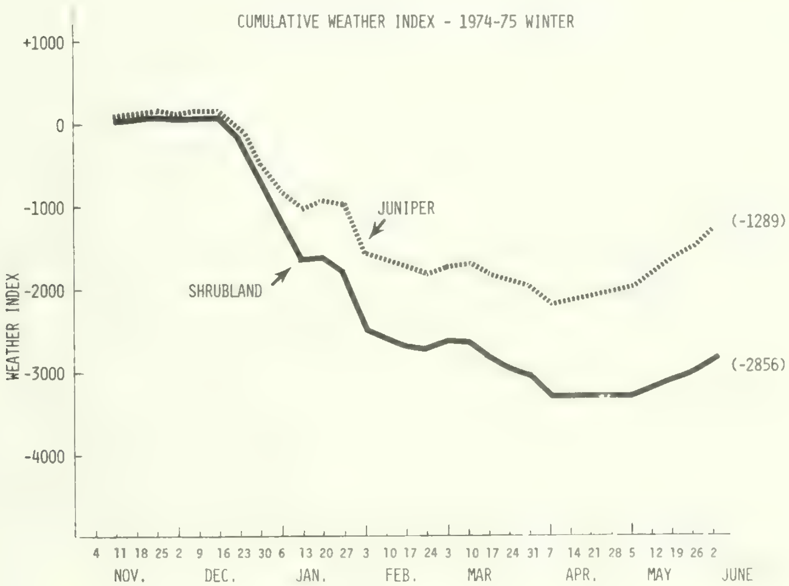

Figure 2.--Cumulative weather index for shrub and juniper cover in the Silver Lake study area, winter 1974-1975.

CURRENT RESEARCH ON PINYON-JUNIPER IN THE GREAT BASIN

Richard O. Meeuwig, Research Forester, and
Robert B. Murray, Range Scientist
Intermountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture
Ogden, Utah 84401[1]

ABSTRACT

Research in progress on pinyon-juniper woodlands in the Great Basin is summarized. The program includes woodland inventory techniques, methods of classifying biotic potentials, use and effects of fire, invasion processes, and methods of revegetation of burned and cutover areas. The goal is increased forage production in harmony with woodland product utilization, soil stability, and recreation.

Keywords: Pinyon, juniper, Great Basin, Nevada.

A number of recent publications summarize results of past research in the pinyon-juniper woodlands of the western United States (Barger and Ffolliott 1972; Clary et al. 1974; Gifford and Busby 1975; Springfield 1976), and a comprehensive cross-referenced bibliography has been assembled by West et al. (1973). However, most of this research was in the Southwest and has limited applicability to the western juniper type. The purpose of this paper is to present a summary of current, unpublished research on pinyon-juniper in the Great Basin. Some of this research should be applicable to the western juniper type and there may be opportunities for coordinating the western juniper research program with the Great Basin pinyon-juniper research program.

To set the stage for our discussion of research in the pinyon-juniper woodlands in the Great Basin, a few words should be said concerning the distribution, extent, and values of the type. There are more than 200 mountain ranges in the Great Basin and pinyon-juniper occurs on most of them. According to estimates made from LANDSAT-1 imagery, there are about 11.7 million acres (4.7 million ha) of pinyon-juniper in Nevada and 4.1 million acres (1.7 million ha) in the

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[1]Located at the Intermountain Station's research laboratory at the Renewable Resources Center, University of Nevada Reno.

Utah portion of the Great Basin (Beeson 1974). Throughout Nevada, the stands are usually composed of varying proportions of singleleaf pinyon (*Pinus monophylla* Torr. & Frem) and Utah juniper (*Juniperus osteosperma* [Torr.] Little), but pure stands of either singleleaf pinyon or Utah juniper can be found in some areas. In Utah, true pinyon (*Pinus edulis* Engelm.) and its hybrids with singleleaf pinyon become increasingly prevalent as one moves eastward. Western juniper (*Juniperus occidentalis* Hook.) occurs in and near the Sierra Nevada on the western edge of the Great Basin.

These woodlands are key winter range for big game. Livestock grazing also has been and is a major use. In many areas, overgrazing of the understory vegetation in the woodland has reduced the forage resource and allowed the density of pinyon and juniper trees to increase. Also, in many areas, the woodland is expanding into adjacent shrub and grasslands, reducing their forage resource. Opinions differ on the magnitude and causes of this invasion; the consensus is that fire exclusion, overgrazing, and perhaps, climatic changes are allowing pinyon and juniper to advance into adjacent communities.

Among the woodland products are pinyon nuts, fenceposts, fuelwood, pulpwood, and Christmas trees. Pinyon nuts have been harvested by Indians for centuries and are still important to their economy. Utilization of the other products is hampered by the high cost of harvesting and transportation. Recreational use of the woodlands is growing rapidly. In addition to game hunting, Christmas tree cutting, and nut gathering, the woodlands are being used more and more for camping, picnicking, rock hunting, and other kinds of outdoor recreational activities.

The main goal of current research on pinyon-juniper in the Great Basin is to obtain information to improve woodland management for increased wildlife and livestock forage production, woodland product utilization, soil stability, esthetics, and recreational opportunities. The research program includes woodland inventory techniques, methods of classifying biotic potentials, an understanding of succession, including invasion dynamics and fire effects, and methods of revegetation of burned and cutover areas.

Development of techniques to measure and predict biomass of singleleaf pinyon and Utah juniper. This is a cooperative study by the University of Nevada and the Intermountain Forest and Range Experiment Station. The objectives are (1) to develop equations to estimate aboveground biomass components from such tree characteristics as stump diameter, tree height, crown diameter, and number of forks; and (2) to obtain data for analysis of growth rates and site quality.

The biomass components include fresh and ovendry mass of wood, bark, twigs, and foliage. These components are determined by actual weighing in the field and ovendrying of samples in the laboratory. Specific gravities are measured to permit conversion of mass to volume. Height growth and radial growth rates of each tree are measured. Slope, aspect, elevation, topographic position, and other site factors are recorded.

Last summer, 50 pinyon and 28 junipers from 13 sites across Nevada were measured. The data have been compiled and regression equations have been developed which show a very good fit of the data. The data base will be doubled this coming field season. The study will be completed and the results submitted for publication by June 1978.

This study is coordinated with the Intermountain Station's Forest Resources Inventory Research unit, which is doing similar work on pinyon-juniper stands on the Carson National Forest in northern New Mexico.

<u>Classification of pinyon-juniper woodlands in the Great Basin</u>. This is another cooperative study of the Intermountain Station and the University of Nevada. Originally, we planned to develop a habitat-type classification system for pinyon-juniper woodlands, including adjacent plant communities susceptible to invasion by pinyon and juniper, and then to quantify the resource potentials of the major habitat types in terms of wood and forage production. However, extensive fieldwork in 1975 indicated that the development of a classification system based on habitat types would be extremely difficult because of the extent of disturbance throughout the type and of doubtful value because the aggressive nature of pinyon and juniper tends to exclude indicator understory species. If a habitat-type classification were developed, it would be subject to considerable error and would probably be too broad to be useful for the quantification of resource potentials.

Since our primary objective is the quantitative evaluation of resource potentials and classification is only a tool, it was decided to reverse the procedure and shift the emphasis from classification to determination of resource potentials in relation to site factors. Once the relations among resource potentials and site factors have been determined, a classification system will be attempted.

In 1976, the study was modified to attempt the following objectives:

1. To develop a model for estimating periodic annual biomass increment of pinyon-juniper stands on the basis of site factors, stocking, structure, and species composition.

2. To determine potential annual biomass increment (resource potential) in relation to site factors by optimizing stocking, structure, and species composition in the above model.

3. To relate potential forage production to potential tree growth.

During 1976, intensive measurements were made on 48 pinyon-juniper stands across Nevada. At least 50 more stands will be sampled in 1977. We also measured productivity and site characteristics of 16 sagebrush stands (*Artemisia tridentata*, *A. arbuscula*, and *A. nova*) within or adjacent to pinyon-juniper woodlands. Measurements of 40 more sagebrush stands are planned for 1977. Analysis and presentation of results will be completed in 1978.

Climate in the pinyon-juniper zone of the Great Basin. Past research and observation indicate that the distribution and biotic potentials of pinyon-juniper woodlands are highly dependent on local climate. Climatic data from within the pinyon-juniper zone are scarce. Most weather stations are in valleys below the pinyon-juniper belt and most storage gages and snow courses are above it. The Intermountain Station is sponsoring University of Nevada research to synthesize models to predict annual and monthly means and ranges of precipitation and temperature within the pinyon-juniper belts. These models are to be based on presently available climatological data. This effort, to be completed June 1978, will augment the classification research described above. We will attempt to correlate growth potentials derived from stand measurements with local climate predicted by these precipitation and temperature models.

Patterns and rates of Great Basin pinyon-juniper woodland invasion and suppression of understory vegetation. This study is being conducted in southwestern Utah by Neil West and Robin Tausch of Utah State University. Its major objectives are: "(1) to identify the patterns and rates of pinyon and juniper tree invasion and the degree of suppression of understory forage species and relate them to site differences by way of a mathematical model; and (2) to develop a means of determining the rates at which acreage has been removed from production in the past and is likely to be removed in the future." This study includes the development of a successional model including both intraspecific and interspecific competition. Several manuscripts are being prepared by Tausch and West.

Controlled fire as a management tool in the pinyon-juniper woodlands of Nevada. This study is a cooperative effort of the University of Nevada, the Humboldt National Forest, and the Intermountain Station. It was started in 1974 to evaluate fire as an alternative to

chaining for removal of pinyon and juniper. The objectives were to determine:

1. When, where, and how to burn safely and effectively.

2. The response of various plant species to various fire intensities as affected by phenological stage and soil moisture conditions.

3. Response of wildlife to fire and vegetation succession following fire.

4. Effects of burning on infiltration rates and sediment production.

This study was conducted on the White Pine Ranger District in eastern Nevada. During the past 3 years, there have been 12 successful burns out of 29 attempts. All of these have been in stands with 3% to 30% tree cover. Stands with more than 30% cover are not suited to control burning because so little understory exists in such stands that the fire must be carried by wind from crown to crown. It is too hazardous to burn when the wind is high enough to carry a crown fire. The requisites for a good controlled burn are light winds (about 5 to 10 miles per hour) and sufficient understory to carry the fire from tree to tree. William Frandsen of the Northern Forest Fire Laboratory in Missoula has been studying the behavior of these fires and is developing a fire spread model.

A final report on this cooperative study was submitted in June 1977. Manuscripts are being prepared for each of the four objectives.

Alternatives in utilization of western juniper woodlands. In cooperation with the University of California and private ranchers, Agricultural Research Service scientists at Reno are studying alternatives for improvement and utilization of western juniper woodlands in Lassen County, California. The alternatives being evaluated are: (1) no treatment; (2) complete conversion to grassland by mechanical control and burning; (3) harvesting wood from 1/4-acre blocks and then seeding; (4) applying picloram to 1/4-acre blocks and then limbing the junipers to facilitate revegetation; and (5) applying picloram to 1/4-acre blocks with no further treatment. All levels of vegetation (the tree, shrub, and herbaceous components) must be manipulated to insure success in revegetation with desirable grasses, legumes, and browse species. The cycling of nutrients from juniper litter and slash is being traced and evaluated in terms of its influence on plant succession and revegetation success. Mule deer use of the various alternatives is being evaluated also.

Revegetation of burned and cutover pinyon-juniper stands. A major portion of the Intermountain Station's pinyon-juniper research effort is devoted to revegetation research. A number of studies are in progress to determine proper species to plant, to improve seeding methods, to reduce rodent and bird depredation of planted seed, and to develop seed orchards. These studies involve cooperation with the University of Nevada, Nevada Division of Forestry, Agricultural Research Service, Soil Conservation Service, the Intermountain Station's Shrub Improvement and Revegetation unit at Provo, Utah, and several other organizations. Field trials for species adaptability and seeding methods are being conducted on the control burns on the White Pine Ranger District and at a number of other sites across Nevada.

Utilization of woodland products. The Nevada Division of Forestry is exploring possibilities for new pinyon-juniper products and markets. They have been particularly interested in whole-tree chips for particleboard, paper products, cattle feed, livestock bedding, and erosion control. Last Spring, Division of Forestry personnel arranged a pilot chipping operation to get an idea of the problems and costs of whole-tree chipping. In the 4-day trial, they found that 50 to 60 tons of green material could be chipped per day at a cost of about $30.00 per ton. When transportation costs are considered, it is unlikely that pinyon or juniper can compete with other sources of chips. However, analyses by Dr. Fred Shafizadeh of the University of Montana show that pinyon and juniper foliage and branches contain a large amount of potentially useful oleoresins. If these oleoresins can be extracted in conjunction with chipping or firewood operations, economically feasible harvesting is a distinct possibility.

Timber harvesting for fuelwood, chips, extractives, or other products is potentially the best way of removing overstory to release understory forage and to permit reseeding. It is particularly attractive where there is a suppressed understory of desired species, such as bitterbrush. It is better than chaining or burning because it yields products of value, it is less damaging to the understory and to soil stability, and it permits selective removal. Unfortunately, harvesting of pinyon and juniper trees is not economically practical at present, except in localized areas close to population centers, because of current market conditions and low volumes per acre. However, we expect the demand for woodland products to increase and, eventually, tree harvesting will be our principal means of removing overstory competition.

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S E C T I O N I I

M A N A G E M E N T

MECHANICAL MANIPULATION OF WESTERN JUNIPER -- SOME METHODS AND RESULTS

Harold Winegar, Regional Habitat Biologist
Oregon Department of Fish & Wildlife
Prineville, Oregon

Wayne Elmore, Wildlife Biologist
Bureau of Land Management
Prineville, Oregon

ABSTRACT

Mechanical manipulation of western juniper (Juniperus occidentalis Hook.) has been performed on 47,700 acres in Oregon. Two methods are briefly discussed including costs, design, vegetative response, site location, livestock and wildlife implications. Methods discussed are single and double chaining and cutting with chainsaws. The discussion centers around juniper control, revegetation, and related resource management.

Keywords: Juniper, revegetation, wildlife relationships, mechanical control.

TWELVE YEARS OF MECHANICAL MANIPULATION, REVEGETATION, AND SOME WILDLIFE RELATIONSHIPS IN WESTERN JUNIPER IN OREGON

Harold Winegar

To date, western juniper (Juniperus occidentalis Hook.) has been mechanically manipulated on approximately 47,700 acres in Oregon. Of these acres treated, 20,258 are private and 27,442 are public. Three mechanical treatment methods or combinations thereof have been used: (1) chaining, (2) dozing and (3) cutting with chainsaws.

The method employed in each particular juniper control project was determined mainly on the basis of cost and understory condition. For example, to treat a large (100+ acre) mature stand on potentially productive soil with trees dominating a decadent understory, chaining

and seeding was usually employed. In treating a small stand (1 to 100 acres with the same site condition), dozing and seeding, seeding and cutting, or cutting, piling and seeding have been employed. In young or mixed age stands containing desired live understory species not requiring soil disturbance and seeding, cutting for understory release was the practice used.

An exception to these criteria was employed by the Bureau of Land Management, Prineville District, on the Bear Creek watershed improvement project. Handcutting was the method used on approximately 6,400 acres with releasable understory, much of which also required seeding. Treated areas were up to 1,000 acres in size. In this case, it was thought that excessive watershed damage might be incurred by chaining or dozing equipment.

Camp Creek Chaining

The first large juniper manipulation project was performed in 1964--the 3,000 acre Camp Creek BLM single-chaining in Crook County. This project was planned and performed primarily for livestock range improvement. About one-fourth pound per acre of bitterbrush (*Purshia tridentata* (Pursh.) DC.) seed, however, supplied by the Oregon Game Commission, was included with grass seed applied aerially for mule deer browse. Additional bitterbrush seed was broadcast, drilled and applied with a Hansen browse seeder on about one-third of the project by the Oregon Game Commission. Bitterbrush and fourwing saltbush (*Atriplex canescens*) seed were also broadcast in juniper root cavities by OGC.

The 3,000-acre chaining was done in three blocks of 800, 1,600 and 600 acres. Growth and survival of seeded bitterbrush was measured for 5 years following the treatment. The average mortality of bitterbrush in all chaining blocks in 5 years was 52 percent. Mortality is estimated to be at least 80 percent at the present time and few bitterbrush plants can be found in the chainings except within fenced exclosures. Saltbush seeding results were nil.

Results of the treatment for livestock grazing have been good. Range surveys were made before and after treatment in the pasture units within which chainings were done. It was estimated that an average change in acres per animal unit month from 22 to 7 occurred within the three chaining blocks. Grazing by livestock has since concentrated within the treated areas which has also resulted in improved range condition within the remainder of the pasture units.

Evaluation of wildlife response was made for deer only by reading 20 one-tenth acre pellet group transects. Ten transects were read within the chainings and 10 in adjacent untreated juniper communities for 6 years following the chaining. The total number of pellet groups counted on all transects decreased by 71 percent in the 6-year period, reflecting population declines which occurred generally throughout mule deer range. Deer were attracted to the treatment for the first 2 years, with a decline in occupancy through the next 4 years. Decrease in deer occupancy within chainings compared to unchained areas was much greater in an 800-acre block on flat table land than in blocks containing numerous draws, ridges, and small patches of standing juniper.

Although significant improvement was made for livestock range, several shortcomings in the treatment layout and method were recognized. (1) Most of the stands chained were of uneven age with a high proportion of young and seedling trees, which were undamaged by chaining. Less than 50 percent of the larger trees were removed from the soil and killed. It now appears that live tree density has increased from pretreatment density. (2) Portions of the area chained could have been improved by grazing management only. (3) Harsh, rocky, unproductive sites were chained. These sites have shown little improvement in forage production, and their principal value as cover for livestock and wildlife was lost. (4) Single chaining did not provide sufficient soil disturbance for good results from aerial seeding. (5) No consideration was given to wildlife cover.

Declining deer populations during the late 1960's prompted wildlife managers to look to juniper control as a means to improve forage on deer winter range. Winter range food was at that time considered by many to be the limiting factor for mule deer.

The trade-offs between wildlife and timber have been specified through northeastern Oregon wildlife habitat management guidelines and findings from the mule deer research project at Silver Lake, from which a physiological definition of deer winter range has been proposed.[1] Winter ranges are those habitats occupied during seasons of the year when deer are either just maintaining body stores of energy or are depending on those reserves for survival. This definition plainly indicates that factors other than food are also important. Conservation of energy reserves can be maintained by having adequate thermal cover in proportion to feeding areas.

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[1] Roberts, R. W. 1975. Project No. W-70-R, Silver Lake Mule Deer Research, Winter Range Habitat Improvement, Job Completion Report.

Some of us were slow to learn. However, in describing methods, costs, and results of some major mechanical juniper manipulations, I attempt to show important changes in project design for wildlife. Although experience was gained from all the numerous projects in which this author and wildlife financing were involved, only certain ones representative of major changes in design and techniques will be described.

Willow Valley Chaining

In the fall and winter of 1967, 1,400 acres of juniper were double chained and aerially seeded between chainings. One-fourth pound per acre of bitterbrush and fourwing saltbush were broadcast in root cavities during February 1968 to complete the treatment. This project, known as Willow Valley juniper chaining and revegetation project, is located near Willow Valley Reservoir on Lost River on BLM lands in Klamath County.

Principal changes in treatment from Camp Creek were seed application between first and reverse chainings and number of species seeded. The species and approximate pounds per acre aerially seeded were: Crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) 8; intermediate wheatgrass (*A. intermedium* (Host.) Beauv.) 1.5; pubescent wheatgrass (*A. trichophorum* C. Right.) 1; Russian wildrye grass (*Elymus junceus* Fish.) .5; sainfoin (*Onobrychis viciaefolia* Scop.) 1; sweet clover (*Melilotus* Mill.) 2; Nomad alfalfa (*Medicago sativa* L.) 1; and bitterbrush (*Purshia tridentata* (Pursh.) DC.) 1. Results of the project were briefly as follows: Control of juniper was considered to be good. Good release of native vegetation occurred. Results were fair to good from seeded grasses but poor from seeded forbs and shrubs. Increase in production of total annuals and perennials, measured after six growing seasons, was found to be 219 pounds dry weight per acre. Livestock grazing was measurably improved. Again, little consideration was given to wildlife cover within the treatment, and no significant improvement in wildlife habitat has been documented. Cost of the project was approximately $15.00 per treated acre.

Harpold and Nine Mile Ridge Chainings

Two large double chainings were performed in 1969, also on BLM lands. These were the 600 acre Harpold project in Klamath County and the 1,100 acre Nine Mile Ridge project in Lake County. In these projects, more emphasis was placed on establishment of forbs and shrubs by seeding. In addition to aerial seeding, shrub seed was applied through seed dribblers mounted over tracks of crawler tractors during chaining operations. This was the first use of tractor-mounted dribblers on juniper control work in Oregon.

The Nine Mile Ridge chaining has been studied as part of the Silver Lake Mule Deer Research by the research section of the Oregon Department of Fish and Wildlife. Since publication of that research work is in progress, analysis, results, or interpretations will not be attempted here. The following description and comments refer to Harpold only.

Bitterbrush seed was applied at 1.3 pounds per acre through four dribblers on two tractors. Species and pounds per acre aerially seeded were crested wheatgrass 2; sainfoin 1.25; small burnet (*Sanguisorba minor* Scop.) .5; bitterbrush .5, and big sagebrush (*Artemisia tridentata* Nutt.) .02. Bitterbrush at approximately one-third pound per acre was broadcast into root cavities.

Climatic conditions in the first year were comparatively unfavorable for seeding establishment, and 125 acres were reseeded by drilling in the spring of 1972. Again, the principal project objective was forage improvement, and little consideration was given to the treatment size, or cover, left within treated areas.

Juniper control was only fair because numerous young and seedling trees were released. Response of native and seeded grasses was considered good. Small burnet establishment was fair. Sainfoin results were poor after the second year. Shrubs per acre after 4 years, including bitterbrush, grey rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Brit.), green rabbitbrush (*C. viscidiflorus* (Hook.) Nutt.) and big sagebrush, average of 14 one-tenth-acre transects was 477. Of this, 39 percent was bitterbrush. Serviceberry (*Amelanchier* Medik.), snowberry (*Symphoricarpos* Duhamel), horse-brush (*Tetradymia* DC.), low sagebrush (*Artemisia arbuscula* Nutt.), and gooseberry (*Ribes* L.) were present on transects, but usually represented by fewer than 10 plants per acre. Total herbage production has not been measured. Again, livestock grazing was improved, but we do not know the over-all net benefits of the treatment. Cost of Harpold, not including reseeding, was $18.00 per treated acre.

North Harpold and Spring Creek Chainings

The 180-acre North Harpold chaining in Klamath County and the 300-acre Spring Creek chaining in Crook County were performed in 1970. Cover requirements for deer received more consideration in the design of these projects. Width of chained openings, especially at right angles to prevailing winds, were reduced to a 400-foot maximum. The width of unchained cover areas left between clearings was usually determined by height and density of trees. Leave area width equal to clearings was a general aim, with a minimum of 150 feet. Numerous smaller openings were interspersed with cover, providing greater edge.

Seeding methods were not changed, except that no shrub seed, other than a trace amount of big sagebrush, was applied aerially.

The following species and pounds per acre were applied on North Harpold: Bitterbrush 3.3 through dribblers and .3 broadcast into root cavities. Crested wheatgrass 2.2, big sagebrush .083, sainfoin 3.3, Ladak alfalfa .28, and small burnet 4.4 were aerially seeded.

Results on North Harpold were briefly as follows: Release of native grasses and establishment of crested wheatgrass was considered good. Frequency of AGDE was found to be from 10 to 80 percent with an average of about 30 percent. Shrubs per acre average of six transects in the third year was 1,210. Bitterbrush and saltbush comprised 90.6 percent and 4.4 percent, respectively. Sainfoin establishment was poor to fair. Small burnet stand is fair to good.

Species and pounds per acre seeded on Spring Creek were as follows: Bitterbrush 1.9 through dribblers and .3 in root cavities, fourwing saltbush .95 through dribblers and .15 in root cavities, crested wheatgrass, sainfoin and small burnet were aerially seeded at 3 pounds each.

Response of native vegetation was good, except perhaps for plants adapted to microclimate under juniper. Crested wheatgrass frequency averages about 30 percent. Establishment of sainfoin was poor, small burnet fair. Shrubs per acre average of 11 transects in the fourth year was 1,797 of which bitterbrush and saltbush comprised 44 percent and .02 percent, respectively.

Although control of juniper was considered to be successful, approximately 30 man-days were devoted to cutting young live trees not killed by chaining, on about one-half the Spring Creek project. Numerous small trees are still growing on the remainder. Control of juniper was more nearly complete on North Harpold, as seems to be the case with other Klamath County projects.

Improved livestock grazing was provided on both projects. Utilization by deer of vegetation in both projects has been noticeably higher than in adjacent untreated areas. However, populations are not known to have been directly affected by the treatments. Parallel population trends are seen generally throughout herd ranges. Total cost of these two projects not including follow-up control efforts was approximately $33.00 per acre treated.

Sheep Mountain and Ward Lake Chainings

The last two major chaining projects were performed in 1971 and 1972; the Sheep Mountain project, 300 acres in Crook County, and 500 acres near Ward Lake in Lake County. Description and results given here

refer to the Sheep Mountain work only. The Ward Lake project is being studied as part of the Silver Lake Mule Deer Research for which publication is in progress.

Sheep Mountain chaining was done in ten separate treatment units within an area about 4 miles long, around the southeast edge of the Maury Mountains. Essentially the same cover considerations were followed in design as were used at Spring Creek. Aerial seeding between chainings, in pounds per acre were: Crested wheatgrass 3, small burnet 3, sainfoin 4, and fourwing saltbush 1. Dribbler seeding, pounds per acre Bitterbrush 3, and fourwing saltbush 2. Growth and survival data collected between 1966 and 1971 on bitterbrush broadcast into root cavities indicated poor results. This practice was, therefore, omitted.

Juniper control again was not complete as numerous live trees remained in treated areas. The average increase in production of combined annuals and perennials, after 2 years, from measurements in four representative pretyped communities was 646 pounds per acre. Over-all net benefits to deer or other wildlife are not known. Total cost of the Sheep Mountain chaining and revegetation project was approximately $41.00 per acre treated.

Chainsaw Cutting

Up to the present time, chainsaws have been used to thin or clear approximately 1,545 acres of private lands and 10,962 acres of public lands. Cost of contracted chainsaw work has varied from $5.00 to $28.00 per acre.

Cover trade-offs have been generally less severe, and where care was used in project layout, cover losses have been negligible. Vegetative results have been generally good and especially good where the most productive sites were selected for treatment. Vegetative production was measured on the 17.5 acre Dairy Hill understory release cutting in Klamath County. Measured in the fourth year following cutting, the increase of combined perennials and annuals was shown to be 436 pounds per acre. The 85 acre Salt Creek drilling and cutting project in Crook County measured in the second year showed an increase in combined perennials and annuals of 274 pounds per acre.

HAND CUTTING WESTERN JUNIPER ON THE BEAR CREEK WATERSHED PRINEVILLE, OREGON

Wayne Elmore

The Bear Creek watershed improvement project, initiated by the Prineville District of the BLM, began in 1973. The primary objective of the plan was to "increase vegetation and litter cover from 45 percent to 60 percent to reduce erosion." Ground cover percentages were derived using the standard "step-toe" transects (Gifford et al. 1973). Percent plant cover-soil loss relationships are based on research by Branson and Owens (1970).

The recommended method was to thin western juniper by hand cutting with chainsaws. Hand thinning prevents damage to native grasses and shrubs and causes less disturbance to fragile soils. The "debris in place" method also provides additional protection by forming small check dams, providing protection for plants from grazing animals.[2] and increases soil moisture by reducing evaporation (Gifford and Shaw 1973). The procedure was slightly altered in 1975 and 1976 with the aerial seeding of crested wheatgrass at 5 pounds per acre on 3,800 acres to help accelerate revegetation on low density sites. To date, establishment of these seedings has been poor, apparently because of the low occurrence of covered seed and low surface soil moisture. Frost heaving was expected to aid in seed coverage but apparently gave little benefit.

Approximately 6,400 acres of cuttings have been completed, with 2,600 planned for fiscal year 1977, and another 3,000 programmed for fiscal year 1978. This will make a project total of approximately 12,000 acres, nearly half of that originally planned. Reasons for the reduction in acreage include: (1) An omission of leave (uncut) areas in the original acreage estimate, (2) most of the highly productive sites have been cut, and (3) large percentage of the remaining areas have a low number of trees per acre (100 or less), making it uneconomical at the present expected cost per acre.

Early cuttings were located on highly productive simas, tub and alluvium soils because these presented the greatest vegetative release potential. Projects have ranged in size from 85 acres to 1,000 acres

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[2] Rollins, M. B. 1973. Bear Creek Watershed Management Plan, Bureau of Land Management, Prineville, Oregon.

with an average of 600 acres. Contract costs varied from a low of $13.00 per acre to a high of $28.00 per acre. No correlation has evolved between the per acre costs and site characteristics. Prices vary with project size, trees per acre, availability and experience of bidders, access to the site, and time of cutting. Projects expected to go high have received low bids and vice-versa.

Project layout, after site location from soils maps, consists of flagging the boundaries in an irregular pattern and designating 10 to 20 percent of the site for leave areas. These leave sites range in size from 10 to 15 acres depending on the topography and the number of trees per acre. Contract specifications also preserved snags, other conifers, hardwoods, and approximately four live juniper trees per acre. The snag and tree provisions were incorporated to reduce visual impacts after heated protests against the project from environmental groups. The leaving of four live trees per acre has not seemingly reduced the total understory vegetative response but does leave a fairly uniform seed source for future reinvasion of juniper seedlings.

Wildlife considerations, primarily mule deer cover areas, were altered from those recommended by the Oregon Department of Fish and Wildlife. They requested approximately 25 percent of the area be segregated into 2 to 5 acre leave areas to help meet mule deer cover requirements. Although total acreage of leave sites closely approaches the desired percentage, the acreage in each leave area was much larger, as previously mentioned.

Major reasons for this diversion were the cost of layout and possible confusion for contractors. Mixtures of irregular leave areas and several colors of flagging develops into a maze for some contractors and a continual supervision problem for the contract administrator.

Advantages and Disadvantages

Problems encountered have been far from crippling, but do present a dollar outlay and should be considered in future project work.

1. Available labor force almost necessitates winter work schedules (winter mill and logging layoffs).

2. Winter projects make effective kills more difficult because snow covers smaller trees and makes falling larger trees difficult.

3. Work days are shorter in winter and more physically demanding.

4. Access to projects is more difficult in the winter. Muddy conditions can also create erosion problems.

5. Down trees present a problem of aesthetics.

6. Down trees draw woodcutters who travel throughout the project increasing soil disturbance.

7. A leave of four live trees per acre is hard to administer and difficult for contractors to judge.

8. Frequency of uncut seedlings, and recovery and regrowth of cut trees is consistently high.

9. Establishment of juniper is obvious on most sites within 2 to 3 years. Transects in cuttings completed in 1973 revealed from 300 to 500 live stems per acre, including seedlings and trees that were felled but not killed during the original project.

10. Maintenance costs to kill establishing juniper, if done by hand, can be very high.

Observed and documented advantages of using the hand cutting debris-in-place method is hard to reference in the literature. Several articles allude to this type of work but little has been recorded outside of chaining, cabling, and dozing (West 1975). Some observations and study results that have been identified as positive developments using the debris-in-place method are:

1. Desirable understory vegetation for watershed protection and livestock forage increased. Studies done by BLM on the Long Hollow thinning, after the third growing season, indicated a vegetative increase from 61 pounds per acre to 357 pounds per acre. Other areas have indicated even greater responses.

2. Data collected to date indicate the primary project objectives of increased litter and vegetation are being accomplished. Ground cover percentages on project site transects versus uncut juniper areas were as follows:

	Vegetative	Litter	Rock	Bare Ground
	- - - - - - - - - - - percent	- - - - - - - -		
Natural Woodland	5 (includes JUOC overstory)	30	4	61
Thinned	30	38	4	28

The above data shows a total ground cover increase from 35 percent to 68 percent. The increase is even more impressive considering that a large percent of the total vegetation in the untreated area is juniper.

3. Debris-in-place removes an insignificant amount of area from production as compared to windrowing in chainings, where up to 40 percent of the land surface is covered, such as in Nine Mile Ridge double chaining.[3]

4. Down trees provide protection for plants from grazing animals, providing a seed source for revegetation.

5. Tree branches provide mechanical barriers slowing runoff.

6. Destruction and disturbance of existing vegetation is minimal.

7. Hand cuttings increased habitat for small mammals. Small mammal trapping data collected by the BLM in the summer and fall of 1976, on thinned and unthinned sites, revealed twice as many species in the thinned sites (six) as in the unthinned (three). There were also 60 percent more individuals trapped in the thinned sites than in the control. Small mammal winter track counts conducted in the same areas reflected a parallel to the trapping data. However, overall net benefits to wildlife are still unknown.

8. Winter bid schedules receive more interest, resulting in more competitive bidding.

9. Available work force generally includes timber workers experienced in the use of chainsaws.

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3 Roberts, op. cit.

10. Down trees and increased vegetation create a situation, seemingly desirable, for control of juniper by controlled burning.

11. Down trees provide mule deer with a food source after needles lose their volatile oils. Usability lasts until needles lose their color and begin to fall from the stem. The period varies with the time of year trees are cut.

SUMMARY

For the past 10 years, papers have been written concerning the vegetative and hydrologic responses to juniper manipulations performed in western States. In most reports, favorable results were shown for increased production of food for livestock and wildlife. Increased AUMs for livestock have been well documented in most juniper control project reports, and livestock benefits are virtually unquestioned. Based upon increased production of vegetation and some observed use of this vegetation by mule deer, great benefits to mule deer and most other wildlife have been assumed. The assumption that equivalent or parallel benefits for livestock and wildlife result from juniper manipulation has not been made. Therefore, for this workshop to develop multiple resource juniper management guidelines, we must rely on the known physiological and sociological requirements of wildlife. Three papers in this workshop are addressed to these requirements in juniper communities for our consideration and use. If we were to design a juniper manipulation specifically to improve wildlife habitat, our principal aims should be: Quality and quantity of food plants, habitat diversity, and retention of required cover.

Points to Consider

1. It was consistently noted with each mechanical manipulation of juniper performed, regardless of the method, results were only partial control. If it is determined both economically and ecologically to have complete juniper control, for better resource management, mechanical methods currently employed are inadequate.

2. It was apparent that chainsaw cuttings, especially after one to two growing seasons, were in a burnable condition. This leads us to consider the combination of mechanical treatment and burning as a more efficient and complete method of control.

3. Crested wheatgrass was shown to provide the greatest contribution to forage production, of all species seeded, in juniper manipulations.

4. Bitterbrush has been successfully established in several juniper control projects. It appears, however, that bitterbrush cannot attain a stature necessary to contribute significantly to the volume of available forage with yearly livestock grazing and current wildlife use. Fourwing saltbush has demonstrated some possibility in this respect.

5. Observations of utilization by deer and livestock of released vegetation indicate improvements in palatability.

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FIRE MANIPULATION AND EFFECTS IN WESTERN JUNIPER (*Juniperus occidentalis* Hook.)

Robert E. Martin, Project Leader
Pacific Northwest Forest and Range Experiment Station
Bend, Oregon

ABSTRACT

Fire has long been part of juniper, shrub, and grass ecosystems. Lightning and Indians were responsible for fires, and juniper generally was less common than today, judging from written reports of early explorers and settlers, and from early photographs (Johnson and Smathers 1976).

What is the relationship of western juniper to fire? How easily is juniper killed by fire? Under what conditions can we burn in western juniper? Survival data of western juniper by size class following four burning prescription levels are given in the paper. Other information on the relationship of western juniper to fire are inferred from work by others in western and other juniper species.

Keywords: Juniper, western juniper, fire, prescribed burning, range, Juniperus, mortality.

FIRE AND WESTERN JUNIPER

Fire will generally retard ecological succession of communities that would move toward a climax of juniper (*Juniperus occidentalis* Hook.) (Adams 1975; Burkhardt and Tisdale 1976; Johnson and Smathers 1976; Martin and Johnson 1978[1]). Other papers in this volume cover more

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[1] Martin, R. E., and A. H. Johnson. 1978. Fire management of Lava Beds National Monument. Paper presented at the 1st Conference on Research in the National Parks. Natl. Sci. Found. and Natl. Park Serv., New Orleans, November 1976. In press.

completely the ecological relationships between fire and juniper. In the early stages of succession when trees are small (less than 6 feet, or 2 meters tall), it is easiest to control the amount of juniper with fire. As trees become larger, more intense fire is generally needed, both to get the fire to spread and to kill the trees. If a site has gone to an essentially closed stand of juniper, it is extremely difficult for us to use fire in the stand under any conditions in which we're willing to burn.

Hall (1973) and Volland (1976) cite several plant communities which may move toward juniper dominance without the disturbing influence of fire or similar agent. We might generalize this in a diagram of ecological succession (Figure 1). In the pioneer stage, grasses and forbs generally dominate. Rabbitbrushes (Chrysothamnus Nutt.) and horsebrush (Tetradymia canescens DC.) may be common, depending on their frequency before burning and availability of seed after burning (Johnson and Smathers 1976, Martin and Johnson op. cit.). As succession proceeds into the seral stages, sagebrush (Artemisia tridentata Nutt). and bitterbrush (Purshia tridentata (Pursh.) DC.) may become dominant, depending on the site. Grasses generally become less prominent, and composition may change from the pioneer types such as bottlebrush squirreltail (Sitanion hystrix (Nutt.) J.G. Sm.), to the wheatgrasses (Agropyron spp. Gaertn.) and fescues (Fescue spp. L.). Heavy grazing may enhance movement toward shrub and juniper dominance and also reduce the frequency and cover of wheatgrass and fescue in favor of the pioneer grasses or the exotic cheatgrass (Bromus tectorum L.). Juniper now appears as scattered trees of varying sizes and ages.

With time, succession would probably proceed to a juniper-dominated climax in which the shrubs and grasses are very much subdued. The juniper stand may now be very resistant to fire except under severe fire conditions. Even light grazing tends to keep the grasses at such a low level that very little fuel exists to carry a fire from one tree to the next.

PREVIOUS WORK

Burning prescriptions to accomplish various management objectives in juniper trees are not well developed, but general guidelines for prescribed burning in range, shrub, and juniper types have been developed. In the Southwest, Jameson (1962) reported 70 to 100 percent of the small juniper killed by fire in his study. Dwyer and Peiper (1967), working in New Mexico, found that fire killed all pinyon-juniper less than 4 feet (1.2 m) tall, but killed 24 percent of the pinyon and 13.5 percent of the juniper taller than 4 feet (1.2 m).

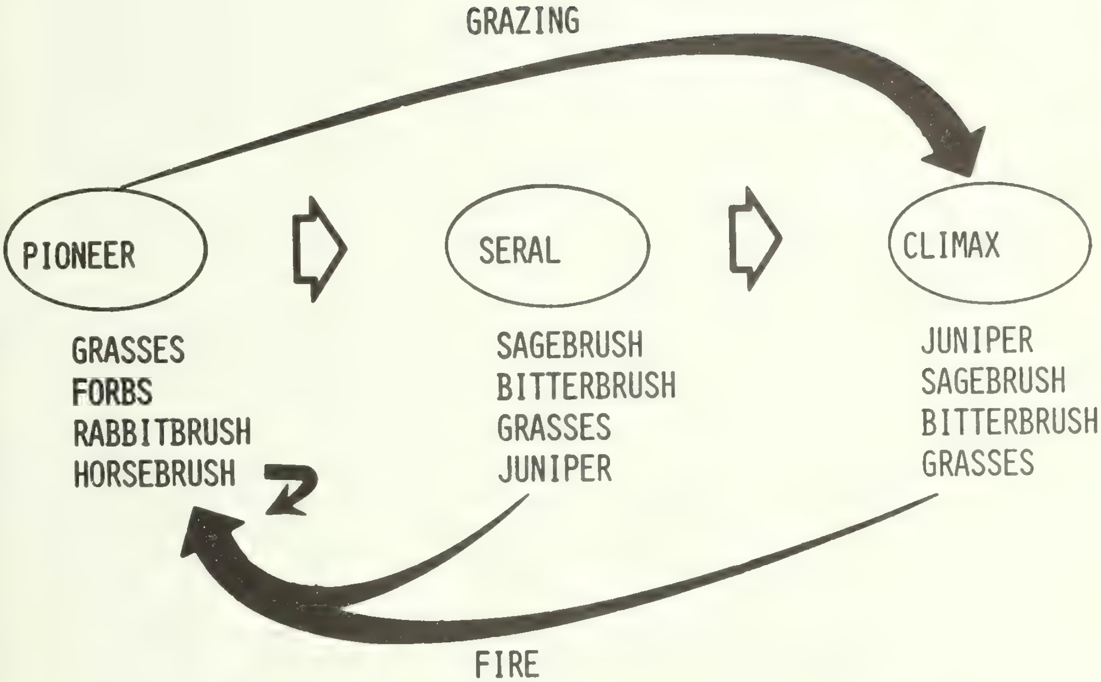

Figure 1.--Ecological succession in many juniper habitats would move from pioneer grass and forb dominated communities through shrub dominated seral stages to a juniper-dominated climax. Heavy grazing may hasten succession, and fire will generally return succession to the early stages.

Dalyrymple (1969), according to Wink and Wright (1973), obtained ashe juniper (Juniperus ashei Buchholz) mortalities of 100 percent in trees less than 2 feet (61 cm) tall, 77 percent in trees 2 to 6 feet (61 to 183 cm) tall, and 27 percent mortality in trees over 6 feet (183 cm) tall when burning in 500 to 1000 lbs/acre (560 to 1120 kg/ha) of herbaceous fuels. The overall average mortality was 68 percent.

Aro (1971) discussed several aspects of pinyon-juniper control. He recommended burning as the most effective and economical means of manipulation. Dozing trees into windrows and seeding grasses was the most effective mechanical treatment with 95 to 100 percent kill. Single chaining killed an average of 30 percent of the trees, and double chaining, 60 percent (see paper by Winegar and Elmore for mechanical treatment of western juniper). Aro also reported one site produced 1300 pounds of grass per acre (1460 kg/ha) after burning compared to 100 pounds per acre (112 kg/ha) on the unburned area.

Wright (1972, 1974) developed prescription limits for burning several range types with and without juniper in Texas. His 1974 publication outlines procedures for setting up and conducting prescribed burns. He recommends burnout of a 400-foot (120 m) strip of grasses and piled juniper on the downwind side under very moderate burning conditions before burning a unit. Relative humidities of 45 to 60 percent are used for burnout and 25 to 40 percent for the main fire. Recommended winds range from 8 to 10 mph (13-16 kph) for burnout and 8 to 15 mph (13 to 24 kph) for the main fire.

Wink and Wright (1973) report that where 1000 kg/ha (900 lb/ac) of fine herbaceous fuels were present only 1 of 368 ashe juniper trees less than 1.8 m (6 ft) tall survived prescribed burns. Many larger trees were killed by the fires, and when 2240 kg/ha (2000 lb/ac) of fine fuels were present, kill was obtained on all trees present. They did not give percentages of mortality.

Blackburn and Bruner (1975) reported on burning in pinyon-juniper types in Nevada. Pinyon-juniper crown cover was 27 and 13 percent of the total area and about 53 and 34 percent, respectively, of total plant cover. Burning was conducted in November with temperatures of 11 to 12° C (52 to 54° F), relative humidities of 26 and 27 percent, winds of 5 to 19 kph (3 to 12 mph). Bruner[2] has used

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[2] Bruner, A. D. 1977. Personal communication. Univ. of Nevada, Reno.

the sum of air temperature, windspeed, and plant cover percent to predict fire spread.

Martin and Johnson (op. cit.) have used winds of 5 to 19 kph 3 to 12 mph) and recommended relative humidities of 15 to 25 percent for burning in western juniper-sage-grass types. Martin and Dell[3] discuss general prescribed burn planning in the Inland Northwest. Frandsen[4] is working with fire spread predictions in pinyon-juniper types occurring in Nevada, where others have used a summation of air temperature (^{o}F), windspeed (mph), and plant cover (percent) to predict fire spread and intensity.

We might consider two extremes which limit our use of fire in western juniper. On the one end, fire will not spread consistently because spaces between fuel concentrations, such as spacing between bunchgrass plants or shrubs, are too great for flame contact to occur and spread the fire. As wind and the amount of available fine fuel in each concentration increase, both the probability of spread and the rate of spread increase. Increases in spacing relative humidity will reduce probability of spread and the rate of spread. Thus, in well stocked bunchgrasses with dead fuels in the bunches, fire will spread under more moderate conditions than it will when spacing is greater, or the grasses are grazed. As we move to the wider spacing usually encountered in shrubs and finally juniper, both higher wind and lower relative humidity are needed. Often, the conditions to burn juniper stands with little grass understory are so drastic (e.g., 35 mph or 55 kph wind) that we would not want to risk burning.

EFFECT OF FIRE ON WESTERN JUNIPER

Our documented prescribed burns in western juniper represent only a limited range of fuel and weather conditions (Table 1), but they provide a basis for managerial use of fire to improve range and reduce juniper (Figure 2). The curves are drawn as percent survival on the vertical scale versus height of juniper on the horizontal scale. The four curves represent survival of juniper the first year after fires under four ranges of conditions. Fuel amounts were similar in

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3 Martin, R. E. and J. D. Dell. 1978. Planning for prescribed burning in the Inland Northwest. USDA For. Serv. Gen. Tech. Rep. In Press.

4 Frandsen, W. H. 1977. Personal communication. Northern Forest Fire Laboratory, Missoula, Mont.

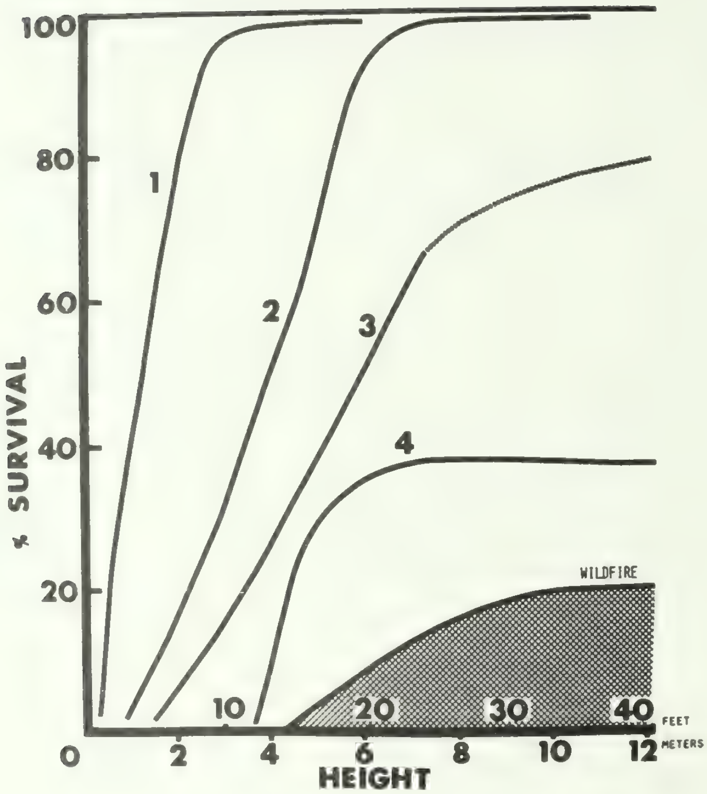

Figure 2.--First year survival of western juniper following four prescribed burning conditions as given in Table 1. Under conditions 1 and 2, survival of larger junipers was nearly 100 percent, whereas only 73 and 37 percent of the larger trees survived the more severe conditions of fires under conditions 3 and 4. General observation of wildfires indicates less than 30 percent survival in most fires.

all areas, and ranged from 1.4 to 4.3 tons per acre (3 to 9 metric tons per hectare) primarily of bunchgrasses, sagebrush and bitterbrush. Some cheatgrass, rabbitbrush, and forbs were also present. Grasses contained high percentages of dead material which provided for fire spread and heat to scorch or ignite juniper crowns.

In all conditions, survival of bunchgrass plants was high, 80 percent or more in the drier burns and almost 100 percent in the wetter burns. Percent cover of grasses was reduced 30 to 50 percent in the first year. Sagebrush in burned areas was killed, as was most gray rabbitbrush (Chrysothamnus nauseosus (Pall.) Brit.). Most green rabbitbrush (C. viscidiflorus (Hook.) Nutt.) was not killed. On burns with high soil moisture, up to 30 percent of bitterbrush sprouted, but never more than 10 percent were left the second year.

Condition 1 was a backing fire under very moderate burning conditions (Table 1). Only small trees were killed consistently by the backing fire, and almost all trees in the 6 to 10 foot (1.8 to 3 m) height class and larger survived.

Fire condition 2 also represents a backfire, but temperatures and winds were slightly higher than in condition 1. Grasses were more abundant, and a burning time in early September contributed to generally drier live fuel and soil moisture. Essentially all trees in the 16-20 foot (4.8 to 6.0 m) height class and larger survived.

Fire condition 3 represents headfiring under slightly more drastic burning conditions. Temperature has increased and humidity decreased from the backfires in condition 2. The season is also early September in the same habitat type as 2. In this condition, essentially all trees in the 1 to 5 foot (0.3 to 1.5 m) class have been killed. Survival of trees greater than 6 feet (1.8 m) tall is roughly proportional to their height. The average highest survival is 73 percent for trees in the 21 to 26 foot (6.3 to 7.8 m) class, but no trees larger than this were present. Probably increased height would not have increased survival substantially, as tree crowns would still have been completely scorched or consumed by the fire.

Condition 4 represents the most severe conditions for which we have any documentation. The season was July with high temperature and very low humidity. Essentially all trees below 15-foot (4.5 m) height were killed, and survival averaged 37 percent in the classes above 16-foot (4.8 m) height. The relatively constant survival of larger size classes indicates that the probability of scorching or consuming the crown of junipers remained about the same.

Table 1.--Prescribed burning conditions related to juniper survival in Figure 2

Conditions		Line number 1	2	3	4
Type fire		Backfire	Backfire	Headfire	Headfire
Temperature	°F	70	70-75	75-85	80
	°C	21	21-24	24-29	24
Wind	mph	5-10	5-10	5-10	5-12
	kph	8-16	8-16	8-16	8-19
Gusts	mph	15	13	15	15
	kph	24	21	24	24
Relative humidity	(%)	25-30	25-30	18-20	10
Habitat type		Juniper/big sagebrush/ bunchgrass	Juniper/big sagebrush/ bunchgrass	Juniper/big sagebrush/ bunchgrass	Juniper/big bitterbrush/ bunchgrass

All the sites reported here had good carrier fuels in the grasses and shrubs present. When juniper stands become closed and carrier fuels die out, or when grazing greatly reduces grass cover, fires will not spread readily except under severe fire weather conditions of high wind and low relative humidity. Burning at this time may be more hazardous than the manager will accept. One alternative is to use chemical or mechanical treatments alone or in conjunction with fire. A second alternative is to condition a wide barrier strip around the area so danger of escape is reduced. A third alternative is to build up carrier fuels by restricting or eliminating grazing 1 or 2 years prior to burning if shrubs and grasses are still present. The last alternative will not work in closed stands. It should be borne in mind that the lost grazing potential may be recovered rapidly in the years following burning. One should also remember that once the area is reclaimed for grasses, future burning should not require such severe weather conditions for fire spread.

SETTING UP A PRESCRIBED BURN

Prescribed burning involves skillful use of fire as planned to meet specific objectives on a given piece of land. Let's look at the different parts.

If you work for an agency, the discussion might begin when the range manager starts looking for ways to increase red meat production on Section 37 or the wildlife manager feels less juniper and more variety in habitat would increase numbers or variety of wildlife. The discussions may then widen to involve other disciplines. More specific objectives are set, such as:

> "Reduce juniper and shrub cover to 20 percent or less" (or to so many stems per acre).
> "Increase forage production to 350 pounds per acre."
> "Eliminate 90 percent of junipers under 10 feet in height."

Prescribing the fire to accomplish the objectives will take some time, and presently we need more data on successful prescriptions. The data in Table 1 and Figure 2 should be helpful.

Eventually, you should develop prescribed burning plans that fit into your total land management planning. These plans will involve many resources and a long-range program of how much you'll burn under what conditions to accomplish what objective.

Next, define the area in which the prescribed burn will take place. Up to this time, discussions may have been general such as prescribed burning of Section 37 (Figure 3A). Now, using maps, aerial photographs,

and the manager's knowledge of the area, detailed boundaries can be set up. Vegetation should be mapped if not already done. Information should be marked on maps, then checked in the field and lines flagged (Figure 3B). Special leave areas which are not to be burned and line problems should be noted. Type of line construction and specifications for lines should be stated. Where possible, existing roads, rocky outcrops, trails, and easy line-building areas should be used. Where line-building is necessary, manual, mechanical, or wet-line techniques (Martin et al. 1977) may be used, the latter techniques being least expensive and non-damaging to the landscape.

Develop a map of the area, indicating all fire lines, special problem areas, firing pattern, and holding crew locations (Figure 3C). Since most areas can be burned under a range of conditions, you might prepare a series of maps with different firing and holding crew plans.

Using a form to consider all aspects of planning, operation and evaluation is very helpful. A planning sheet such as that offered by Martin and Dell (op. cit.) can be helpful.

It's important to begin planning Environmental Analysis Reports early so approval can be granted. The EAR also helps you to discover new facets of fire effects you should be considering in your prescription.

You decide your objective will be to remove 60 to 90 percent of the juniper under 15 feet (4.5 m) but retain 90 percent of juniper over 15 feet (4.5 m). Another objective will be to save 90 percent of the bunchgrass plants.

From the objectives, you can use Figure 2 and Table 1 to arrive at prescription levels, assuming the fuels are similar. You decide on the following conditions.

Season	:	June or September
Precipitation	:	0.5 inch (1.3 cm) or more within week if September burn
Relative humidity	:	17 to 23 percent
Temperature	:	65-80^{o} F (18 to 27^{o} C)
Wind	:	5 to 12 mph (8-19 kph) Gust to 15 mph (24 kph)

The firing pattern will be to backfire 100 feet (30 meters) on the downwind side except where backed by lava flows (Figure 3D). Strip headfires will then be used to burn the next 100 feet (30 meters) and the southern fourth of the unit (Figure 3E). Finally, a headfire will be lighted to spread entirely across the unit (Figure 3F).

Holding and burning crews consisting of the following will be located as indicated on map.

2 - 200 gallon pumpers (T1, T2)
1 - 500 gallon pumper (T3)
2 - 10 man holding crews with hand tools
1 - weatherman
radios in vehicles and 2 for each 10-man crew
3 - burners with drip torches and radios
1 - burning boss

As burning progresses, you'll move your crews so they're in better position should trouble occur (Figure 3D-F).

More details could be put in here, but consulting other publications, observing prescribed burns, and assessing one's own needs by beginning with smaller fires will probably be more useful. Evolving different plans can eventually lead to more effective, less expensive burning.

You've decided on a specific piece of land for burning, decided on prescribed burning objectives to meet overall land management goals, and have planned the burn. The prescribed conditions have arrived, so it's now time for your skillful application of fire. It has to be just that! You'll first want to try a small test fire where you'll begin backfiring (Figure 3D). If the fire fails to spread satisfactorily, you will have to postpone burning until the fuels dry some--later in the day or week. When conditions are too wet or calm, you may spend all day trying to burn and never get an adequate fire. If the fire spreads too rapidly, tends to spot, or consumes too much fuel, put it out. These conditions may be too dangerous for prescribed burning or damaging to the vegetation and soil. It's generally less expensive in the long run to wait for conditions to give you the fire you want. Remember, the fire is the final integrating factor of all the elements in the prescription.

If you decide to keep burning, adjust your burning to get the fine tuning you want. Once you have a black line established, perhaps you can go to very narrow strip headfires to speed things up and keep costs down. Be sure the fire is what you want. Keep watching it. Don't speed up to save money or because you're impatient--and in doing so fail to meet your objectives. Also, don't mechanically follow through your plan; adjust as conditions and fuels change. Remember--skillful application!

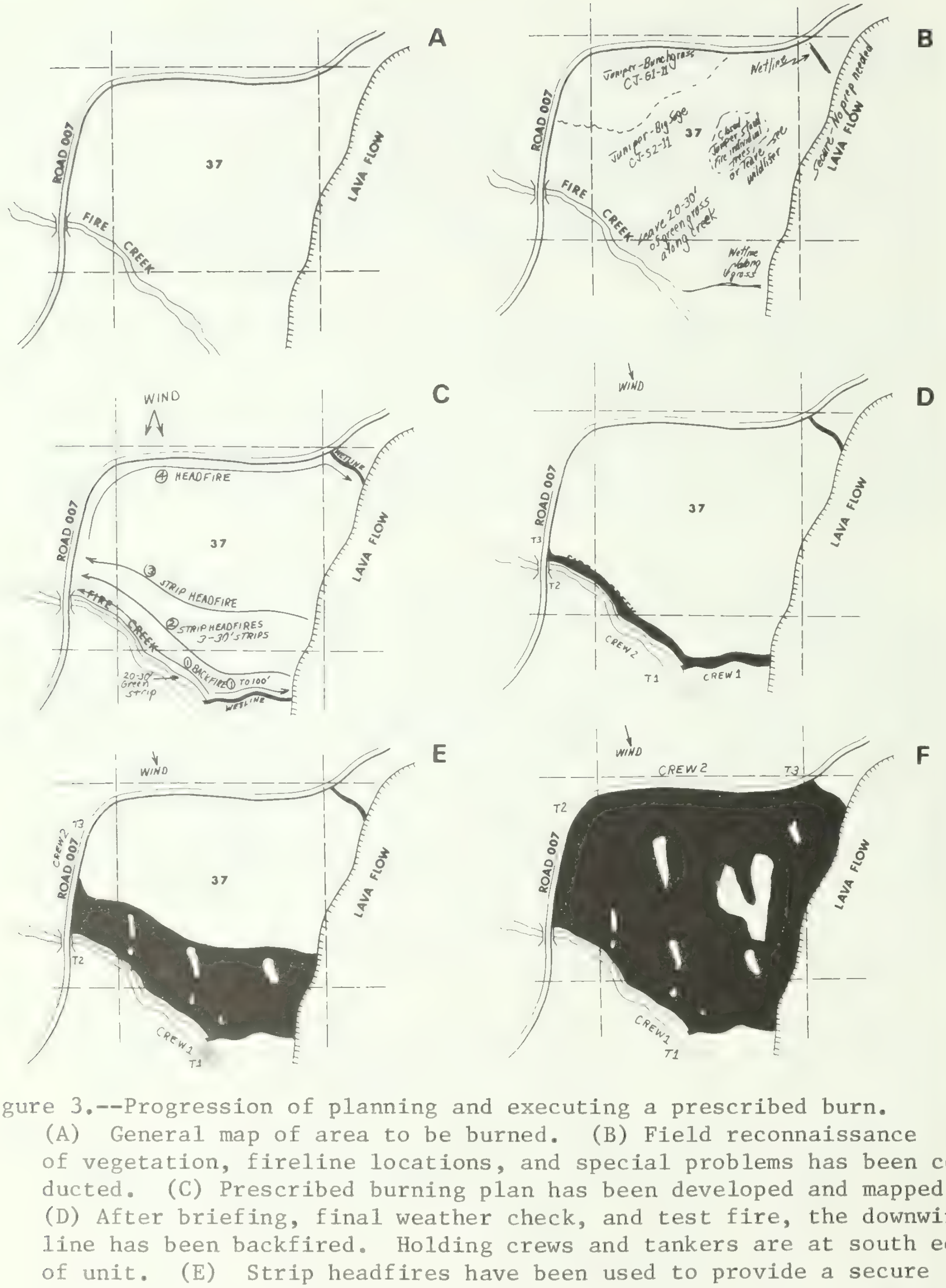

Figure 3.--Progression of planning and executing a prescribed burn. (A) General map of area to be burned. (B) Field reconnaissance of vegetation, fireline locations, and special problems has been conducted. (C) Prescribed burning plan has been developed and mapped. (D) After briefing, final weather check, and test fire, the downwind line has been backfired. Holding crews and tankers are at south edge of unit. (E) Strip headfires have been used to provide a secure line: some interior areas have not burned, as expected and desired, but present no fire control problems. (F) Headfire has been used to burn out entire unit. Holding crews and tankers have been moved to new positions. Unburned areas will provide habitat diversity for wildlife.

COSTS OF PRESCRIBED BURNS

Costs of prescribed burning can be quite variable, depending on conditions. Beginning a prescribed burning program in range areas is much cheaper than beginning in timbered areas. As crews are trained and develop experience, and as the areas to be burned become better conditioned, costs drop dramatically.

Costs should include those for planning, preparing, and conducting the burn. Early in a program planning, costs will be high; however, once a plan for a district or large area involving several sequencing burn units is developed, only minor adjustments in the plans may be necessary. Preparation for burning will decrease as more effective techniques are developed. Old burning lines may be used for subsequent burns with only minor reworking. Even where new lines are made, difficulty in constructing the lines may be easier because of less fuel and better accessibility. Costs of conducting the burn should drop because of training and experience, lower fuel load, and lower chance of escape, or of damage should escape occur.

Costs of burning given by various individuals and organizations vary due to factors considered, pay scales, size and condition of areas, and the stage of burning program. Where mechanical treatment is needed in closed stands, costs will be much higher (see paper by Winegar and Elmore in this volume). For a well-established program of range burning where fine fuels will carry the fire, costs should be under $1 per acre. Little revision of plans is necessary, firelines are established, fuel-loadings are not high, crews are trained, and danger of escape is low. All these factors contribute to lowering costs.

MANAGEMENT GUIDELINES

Based on what has been presented here and in other papers, we can make some general statements concerning what is presently available for managers who wish to use fire in manipulating western juniper.

1. Prescribed burning can be used inexpensively and effectively to control western juniper encroachment.

2. Conditions and data given in Table 1 and Figure 2 can be used as preliminary guides for prescribing fires in western juniper types where herbaceous plants and shrubs will carry the fire. Experienced fire personnel should conduct the burning.

3. Prescribed burning entails:

 a) Describing piece of land and its boundaries.

b) Defining prescribed burning objectives to meet land management goals.
c) Setting prescription and planning to meet objectives.
d) Skillful and observant application of fire.

4. Costs are variable, but drop dramatically as prescribed burning programs develop. Costs range from less than $1 per acre to over $10 per acre for range burning.

RESEARCH NEEDS

Although general information is available concerning the effects of fire on western juniper communities, there is need for specific effects of fire on the soils, plants and animals in these communities. We also need to know more about the fuels, fire behavior and fire prescription in juniper communities. I would list research needs as follows:

1. Effects of fires on juniper under a wide range of prescribed burning conditions.

2. Effects--short and long-term--of fire on associated vegetation under a wide range of burning conditions.

3. Develop prescriptions and methods for burning juniper, perhaps in conjunction with mechanical treatment, where little or no carrier fuel exists between trees.

4. Develop biomass estimates and fuel characteristics for western juniper.

5. Develop estimates of the effect of juniper on growth of associated species.

6. Describe the effects of prescribed fires on soils, nutrients, water, and air in western juniper ecosystems.

7. Describe the effects of prescribed fires on various wildlife species.

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WESTERN JUNIPER MANAGEMENT FOR MULE DEER

Donavin A. Leckenby
Oregon Department of Fish and Wildlife
La Grande, Oregon

ABSTRACT

As managers of the western juniper woodland, we need flexibility to meet the changing needs of society. We should adopt rationales that dictate management prescriptions which preserve the ecosystem even though our goal is to benefit a featured species such as mule deer. Effective planning and implementation must draw upon interdependencies among behavorial and physiological requirements of animals, preserved diverstiy of plant communities, and the multiple-use sustained-yield concept. In order to effectively manage habitat for a deer herd, the needs of the subpopulation and the individual respectively must be met within the home ranges they traditionally occupy. Annual cycles of reserve storage and depletion document how well habitat quality meets the daily physiological requirements of mule deer. Occupancy of habitats by deer illustrates how management for preserved diversity of plant communities and successional stages will provide options that maintain or enhance productive survival of mule deer subpopulations; forage quality helps deer endure weather stresses; structure of cover types diminishes the severtiy of weather. Though commonly considered to be browsers, deer are in fact opportunistic foragers; they eat the best that is available under prevailing conditions. Browse is not digested quickly enough to compensate for energy losses due to severe weather stress; at such times, cover becomes critical because it helps lessen drains on body reserves. Since the microclimate can be predicted from vegetation height, crown closure, crown depth, stem size, and stem density, cover quality can be measured. If knowledge is sufficient to indicate that juniper control is necessary, created openings should average between 5 and 10 tree heights in width, but should not exceed 120 meters. Managers should plan for about 40% of the subpopulation range in cover and 60% in forage areas. The relative values of cover and forage must be carefully weighed when management decisions are made. To approach mutiple-use management of the western juniper woodland, we need to simultaneously consider the multitude of products and their many

interdependencies which constitute the ecosystem. Future research should address those facets of the system which are now vaguely perceived.

Keywords: Western juniper, mule deer, subpopulations, behavior, physiology, microclimate

INTRODUCTION

One of our obligations to future generations is to preserve options that we may think are not viable. We all face problems today which did not exist 15 years ago. We, as managers, need flexibility to meet the changing demands of society. By preserving our management options (Bella and Overton 1972) we gain the flexibility required for responsible, long-range management of western juniper (Juniperus occidentalis)[1] communities. We should develop rationales that lead to management prescriptions which preserve the ecosystem even though our goals are to benefit a featured specie; mule deer (Odocoileus hemionus hemionus). We should examine rationale behind each program and determine why it is desirable for mule deer management over the long run. I will present such a rationale and prescription for management of western juniper communities to meet the requirements of mule deer. To be effective, planning and execution must address the following: 1) behavioral and physiological needs of deer, 2) diversity of plant communities, and 3) multiple-use, sustained-yield concepts. The following discussion is an interpretation of the literature, plant communities, and mule deer which constitutes a rationale for management of western juniper communities for the benefit of deer.

We traditionally think of herds and ranges of deer, but we should think of mule deer subpopulations (Leckenby a., in manuscript) and the parts of the ranges they traditionally and exclusively occupy. Basically we can not effectively manage habitat for the entire herd unless the needs of the individual and the subpopulation are met.

Deer in general exhibit an annual cycle where nutrient storage precedes reserve depletion. Animals are exposed daily to variable periods of energy gain, balance, and loss due to the interplay between forage quality and weather stress. Severity and length of weather stress are diminished by plant community structure, but each community protects deer only within a limited range of conditions. Since the value to deer of each community changes with weather severity, habitat diversity is insurance against the uncertainties of weather. Their use of habitat illustrates how managing for diversity of plant communities will preserve options for maintaing or enhancing productive survival (Leckenby a., in manuscript; Leckenby and Adams, in manuscript) of mule deer subpopulations.

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[1] Plant names according to: Hitchcock, C. Leo and Arthur Cronquist, 1973. Flora of the Pacific Northwest, an Illustrated Manual. Univ. of Washington Press, Seattle and London, 730 p.

To benefit mule deer and justify management efforts, programs for western juniper communities should include the following points: 1) We should examine how all resources in the area will be affected over time. 2) We should focus on subpopulation home ranges as the basic management unit. 3) We should adopt the plant community and successional stage as a habitat planning unit. 4) We should seek to maintain or enhance plant community diversity within each basic management unit. 5) We should focus on each vegetation stand as a treatment unit. (Vegetation stand is defined as the concrete example of a plant community as observed in the field; stand is not used in the traditional sense, i.e., a forest stand (Figure 1). 6) We should manipulate only where knowledge shows what is specifically lacking--forage, cover, or both. 7) We should first examine the option to maintain or enhance forage without altering the structure of the original vegetation stand. 8) If that option (i.e. 7) is not viable, then in order to retain management flexibility which can accommodate future options, we should leave enough of the vegetation stand untreated to maintain its essence. 9) We should make treatment widths multiples of tree heights and manage for a minimally acceptable level of energy stress over time.

Research is needed to increase predictibility and effectiveness of western juniper management for benefit of mule deer.

RATIONALE FOR MANAGEMENT

Requirements of mule deer should be examined and provided for if management of western juniper is to be beneficial. A management unit should be large enough to accommodate the behavioral patterns of a subpopulation. Size, interspersion, composition, and structure of plant communities within management units should accommodate the deer's physiological traits. Management should provide for community diversity to meet varying forage and cover requirements of deer throughout the seasons. To attain maximum benefit from vegetational manipulation, structural features of communities should be preserved.

Subpopulations and traditional ranges

Habitual behavior confines subpopulations to their traditional areas even though better habitat may exist in other parts of a seasonal range. Of 300 plus deer marked on the Silver Lake and Fort Rock winter ranges between 1959 and 1969, about 90% of the retrappings and sightings were made within two miles of the initial capture site (Leckenby a., in manuscript). Locations of marked deer, extremes over the years, were aligned across elevational contours and were concentrated in a small area, about one and one-half by four miles (Figure 2). Sightings of individuals within years further emphasized fidelity for specific areas of the winter range (Figure 3). Research conducted elsewhere in Oregon and other states presents evidence compatible with subpopulation and traditional range hypotheses (Bright 1966, 1967; Cronemiller and Bartholomew 1950;

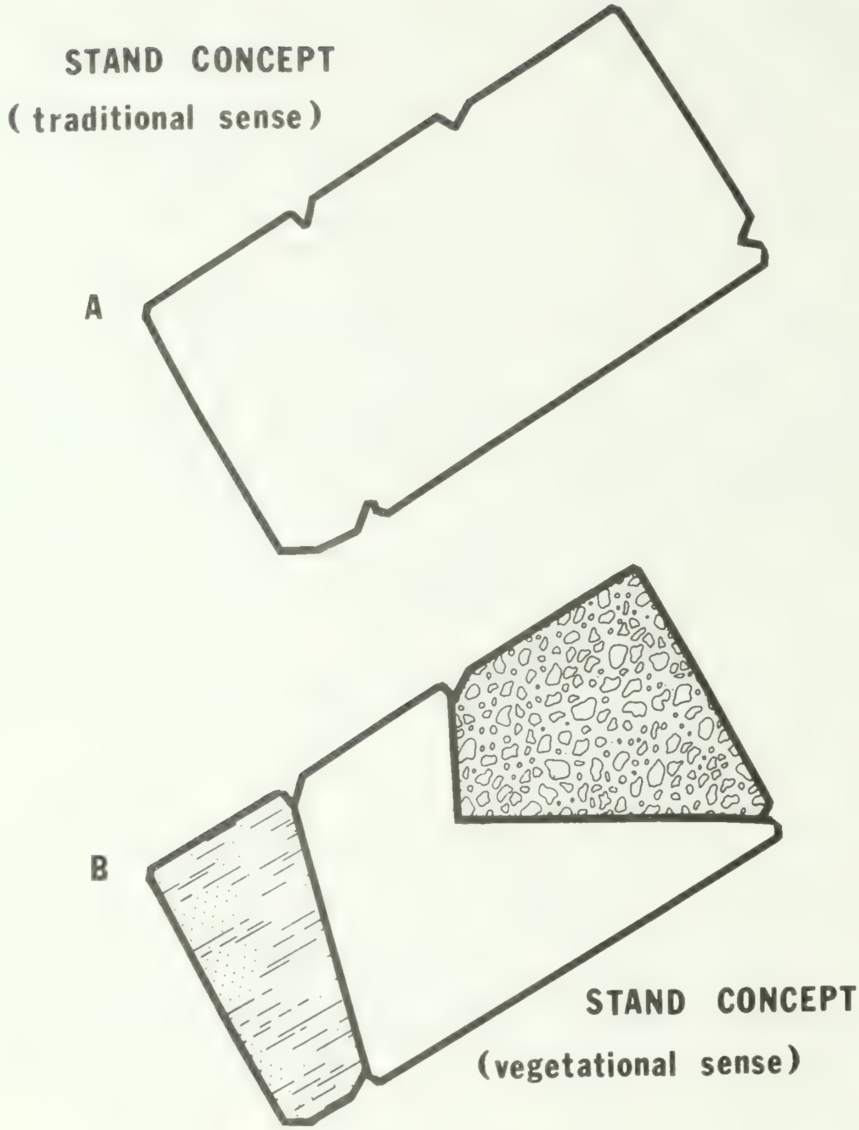

Figure 1. A woodland stand in the traditional management sense consists of a continuous grove of trees (A). The same woodland stand in the ecological sense generally contains vegetation stands which belong to different plant communities (B).

Dasman and Taber 1956; Gruell 1958; Linsdale and Tomich 1953; Mackie 1970; Murie 1940; Terrel 1973; Wallmo and Gill 1971; Zalunardo 1965).

Subpopulation home range appears to be a discrete unit within which to manage western juniper for deer on winter and summer ranges; each should be mapped separately. Management for each subpopulation should

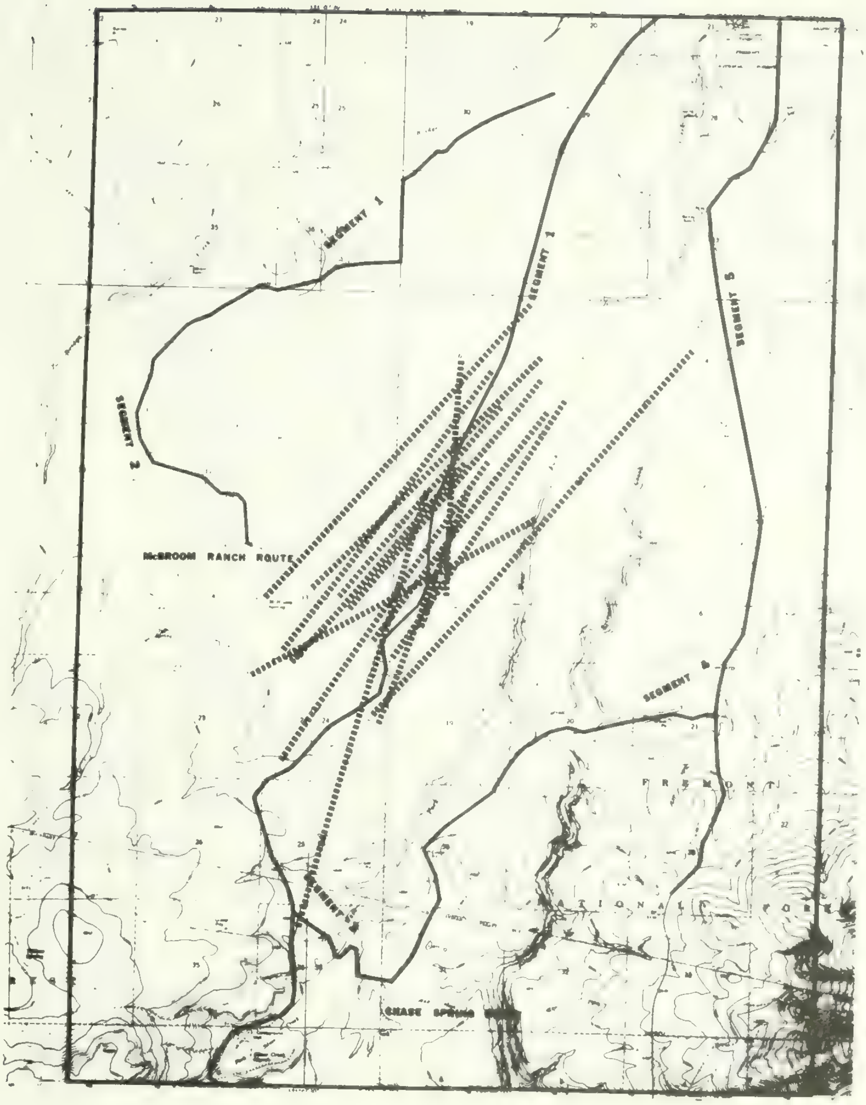

Figure 2. The size and location of a mule deer subpopulation winter range is suggested by the greatest linear distance between sightings for several individual deer. Although only the extreme locations are connected, there are more than two sightings for each individual.

maintain plant community diversity over time in order to accomplish the following: 1) to preserve management flexibility that can accommodate future options, 2) to accomplish multiple-use objectives as dictated by law, and 3) to provide for physiological needs of deer within subpopulation ranges.

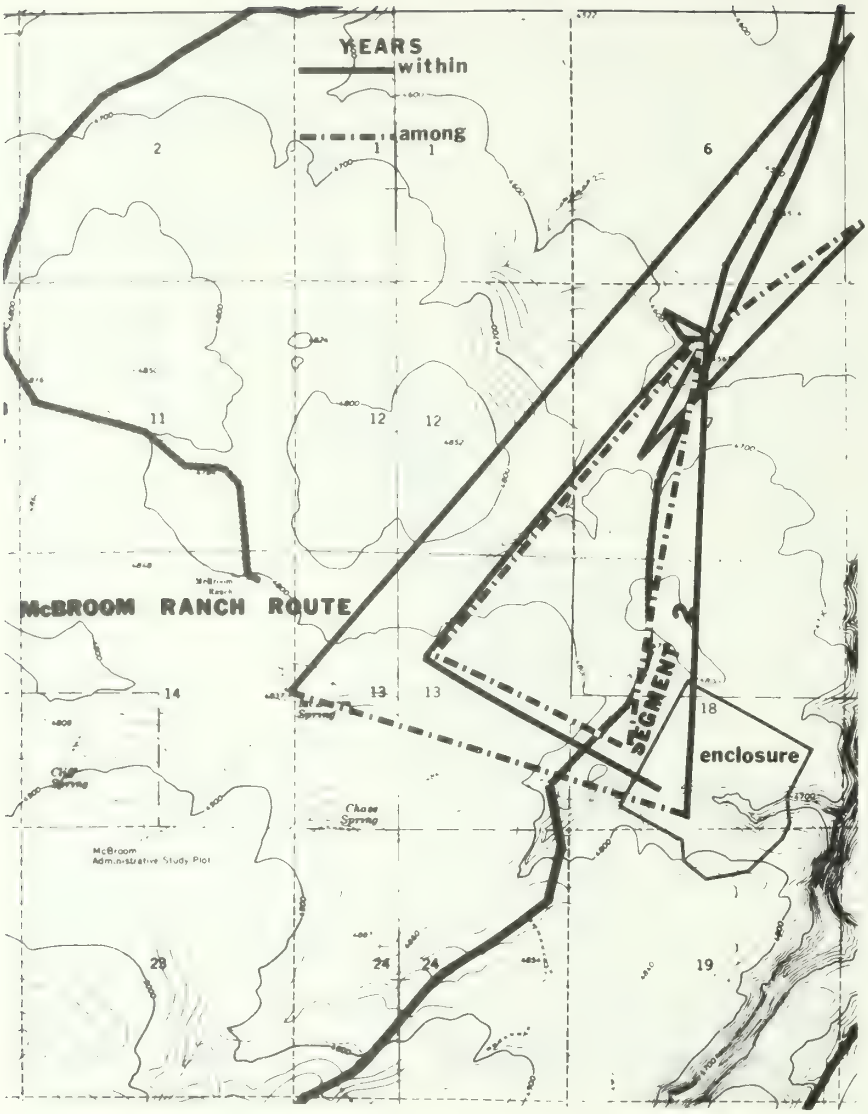

Figure 3. Individual mule deer returned to a subpopulation range for several years. They frequented the entire area, but showed centers of concentrated occupancy.

Physiological responses

Productive survival of a mule deer subpopulation is dependent upon how well and how often physiological needs of the individuals are met. Dead deer do not contribute to population growth; they contribute to the ecosystem only by recycling of nutrients. There are, however, various levels of aliveness (Moen 1973). 1) A deer may be barely surviving (not contributing to maintenance of a subpopulation) and thus only using

resources from the ecosystem. 2) A deer can be maintaining itself and contributing to the subpopulation because it reaches sexual maturity in two years instead of three and it may successfully produce one fawn where the first deer produced none. 3) An idividual may be doing well and is maintaining the subpopulation because it reaches sexual maturity in one year and produces three fawns. This scale of aliveness illustrates what I term productive survival. In essence, the quality of the habitat determines the level of productive survival.

Mule deer follow an annual cycle of energy storage and reserve depletion caused by hormonal and nutritional balances (Wood et al. 1962; Wood and Cowan 1968; Robinette et al. 1973). Timing of the body-weight cycle is known to be related to breeding and lactation periods (Figure 4).

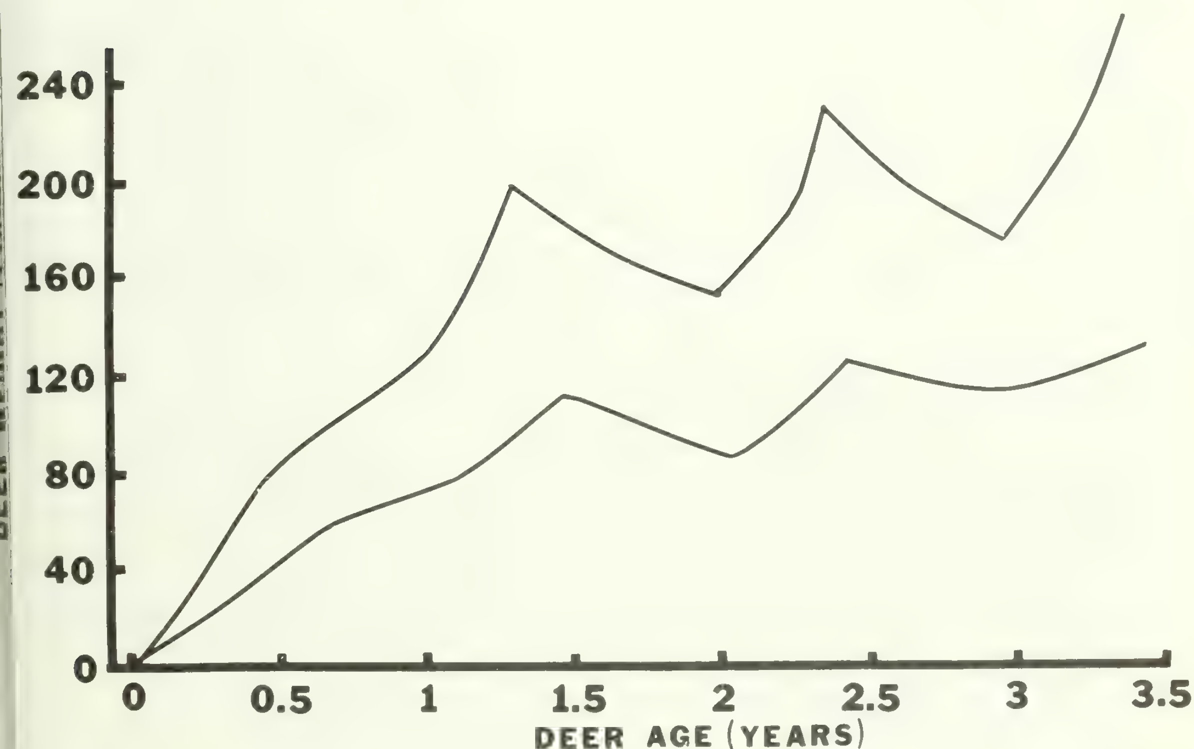

Figure 4. Wild ruminants generally and mule deer specifically undergo seasonal cycles of body weight which reflect physiological adjustments to changing nutritional opportunity. The quality and quantity of forage and cover within two subpopulation's annual ranges are suggested by these generalized weight curves which express moving averages of daily gains and losses of nutrients and energy.

Magnitudes of weight changes are determined by forage quality, particularly available energy (Moen 1968; Nordan et al. 1970; Short et al. 1969). The lower curve (Figure 4) typifies a deer somewhere between the first and second levels of productive survival; whereas, the upper curve suggests a deer approximating the third, highest, level of productive survival. Poor quality forage plus environmental stress contribute to large, rapid losses of reserves irrespective of time of year. Poor quality cover permits environmental stress more frequently and for longer periods. Changes in body weight of all age classes reflect how well forage and cover balance energy losses to (and gains from) the environment.

The annual cycle of weight and condition is the net average of daily changes in energy gain, balance, and loss. Potential losses of condition from stress at various times each day are moderated by forage quality, particularly energy content. There must be a surplus of energy beyond the daily maintenance requirement, otherwise productive processes or storage of reserves are not possible. The energy required to maintain a deer each day is largely, but not only, determined by heat loss to the environment (Figure 5). Like us, mule deer must keep their body temperature (39°C, 102°F) within narrow limits or they die. As conditions create more extreme heat drains, deer must metabolize more reserve energy to maintain their internal temperature. At some point the effective temperature (analogous to wind chill versus measured air temperature) becomes either too hot or too cold for the deer to find adequate forage or cover; then, and for as long as such stress persists, productive survival of the individual declines (Blaxter 1962; Brody 1945; Brody 1956; Kleiber 1961; Moen and Jacobsen 1974; Moen 1976; Porter and Gates 1969; Silver et al. 1969; Silver et al. 1971).

Observed occupancy of plant communities

The adequacy of forage and cover for each subpopulation is limited by diversity, amount, and interspersion of plant communities within a subpopulation's traditional range (Duffey and Watt 1971). Occupancy of plant communities by mule deer reflected changing needs for forage and cover in different seasons and with daily vagaries of weather (Leckenby b., in manuscript). Mild weather was associated with considerable use of grassland plant communities (Leckenby and Adams, in manuscript) (Figure 6). These communities were forage areas containing highly nutritious foods at critical times, but such stands offered no cover from stress of cold or hot environments. Thus, occupancy of open habitats was inversely correlated with weather severity. Use of shrubland communities did not fluctuate so extremely (Figure 7). The pattern was similar to occupancy of grasslands, but minimal use occurred later in the season (Figures 6 and 7). Shrublands were forage areas too, but they offered more cover against temperature and wind stress than could grassland communities. Juniper communities were primarily used when deer needed protection from extreme weather severity (Figure 8). Western juniper stands provided cover analogous to cedar-swamp deer yards (Ozoga 1968; Verme 1965), in that wind velocity was reduced, temperatures were

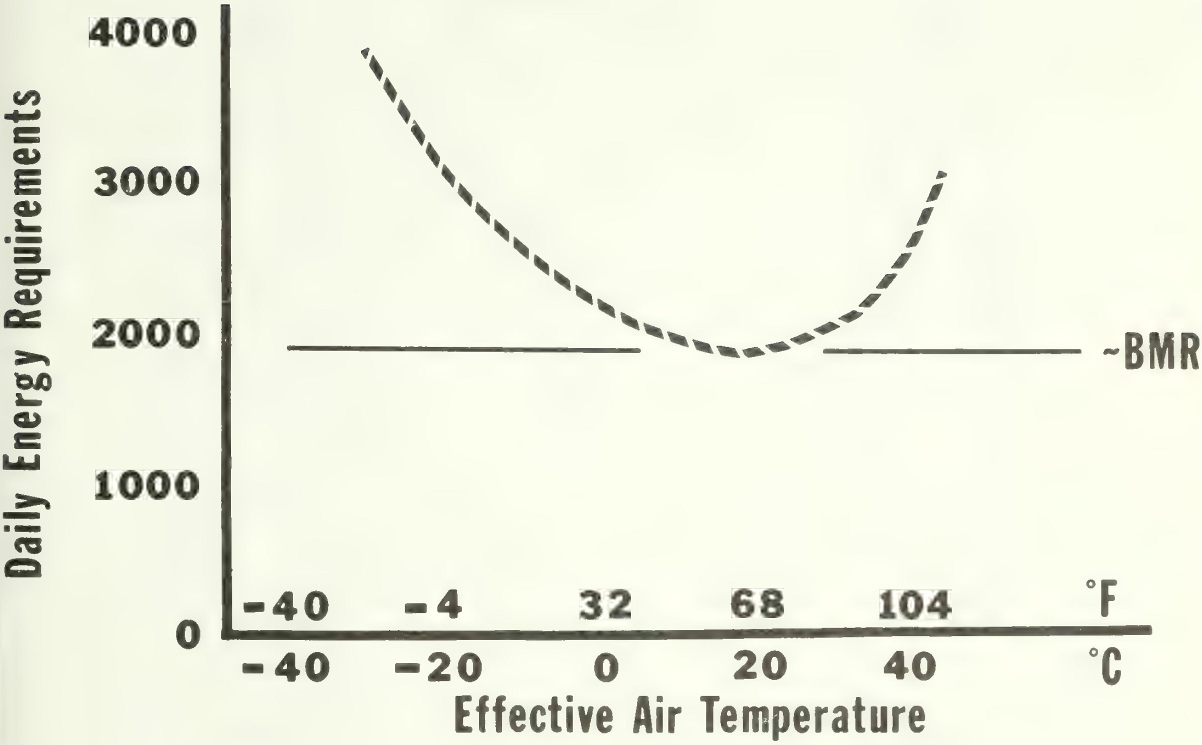

Figure 5. Daily energy requirements of ruminants generally and mule deer specifically increase as effective temperature becomes too warm or too cold. The energy demand at any instant is the sum of requirements for body maintenance (similar to basal metabolic rate, BMR, of humans), body temperature regulation (compensation for heat lost to the environment), and body growth (including storage of fat reserves). Effective temperature represents the combined influence of weather factors on energy flows between an animal and its environment.

more stable and less extreme, and snow conditions were less severe than in adjacent shrubland (Bright 1976; Leckenby and Adams, in manuscript). Most juniper communities contained little forage, but they provided the best protection against thermal stress, and occupancy was positively correlated with weather severity (Leckenby and Adams, in manuscript).

The central importance of western juniper stands on two winter ranges was emphasized by the deer's differential occupancy of plant communities. Results from those areas were comparable, suggesting a prediction factor useful in management (Figure 9). Occupancy of grassland and shrubland communities was strongly correlated with the forages they contained. Conversely western juniper communities were occupied to the same degree regardless of forage--suggesting their value was cover oriented. The value of plant community diversity within subpopulation ranges was therefore demonstrated.

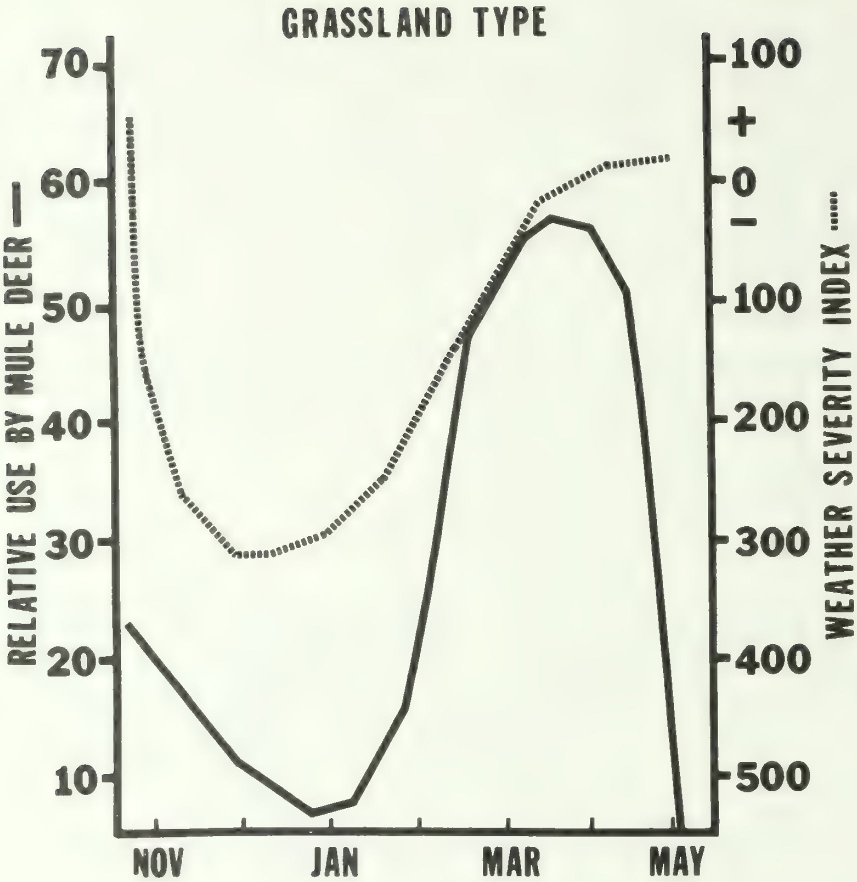

Figure 6. Mule deer occupied grassland type communities principally when young forage was available and effective temperature was least stressing (when weather severity indices averaged less than - 150). The weather severity index was constructed from temperature, wind, and snow measures to approximate effective temperature and consequent heat losses of deer. Relative use calculated as (deer per acre in type/total deer per acre all types) x 100.

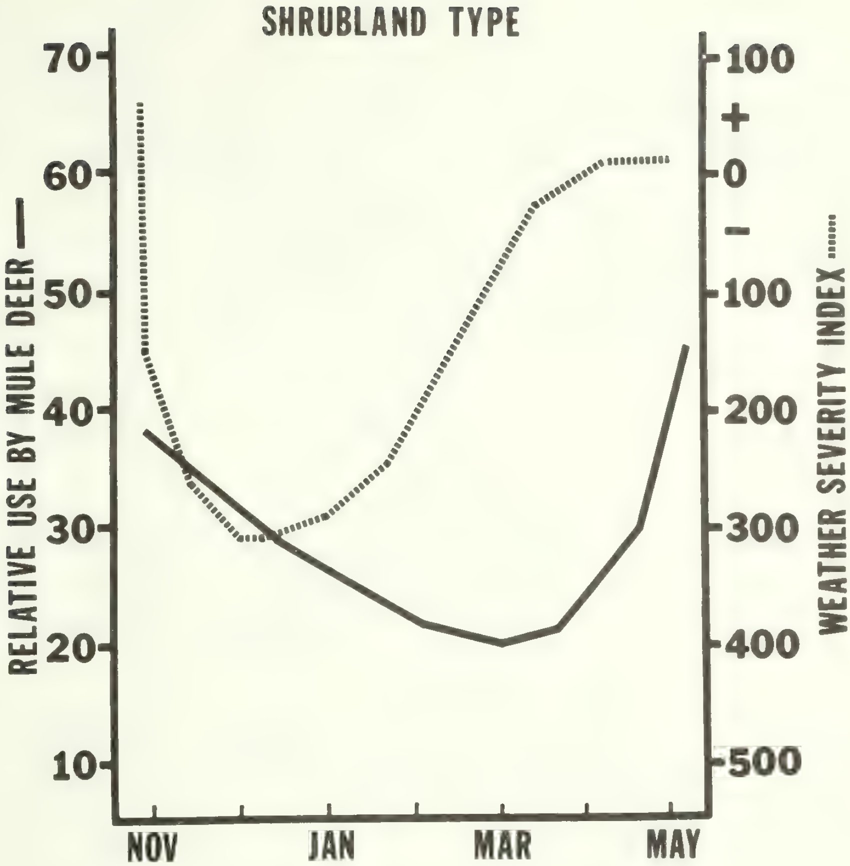

Figure 7. Mule deer occupied shrubland type communities principally when these stands provided the best forage and effective temperatures increased the need for cover (when weather severity indices averaged greater than - 150). The weather severity index was constructed from temperature, wind, and snow measures to approximate effective temperature and consequent heat losses of deer. Relative use calculated as (deer per acre in type/total deer per acre all types) x 100.

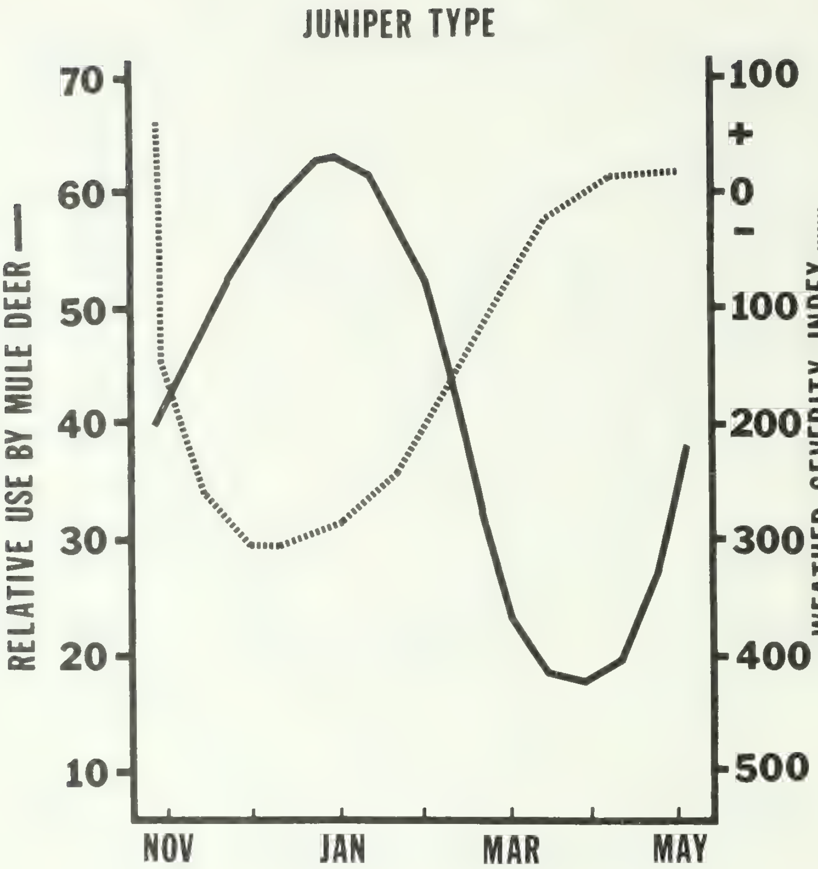

Figure 8. Mule deer occupied juniper type communities when the woodlands provided protection from stressing effective temperatures (when weather severity indices averaged greater than - 200). The weather severity index was constructed from temperature, wind, and snow measures to approximate effective temperature and consequent heat losses of deer. Relative use calculated as (deer per acre in type/total deer per acre all types) x 100.

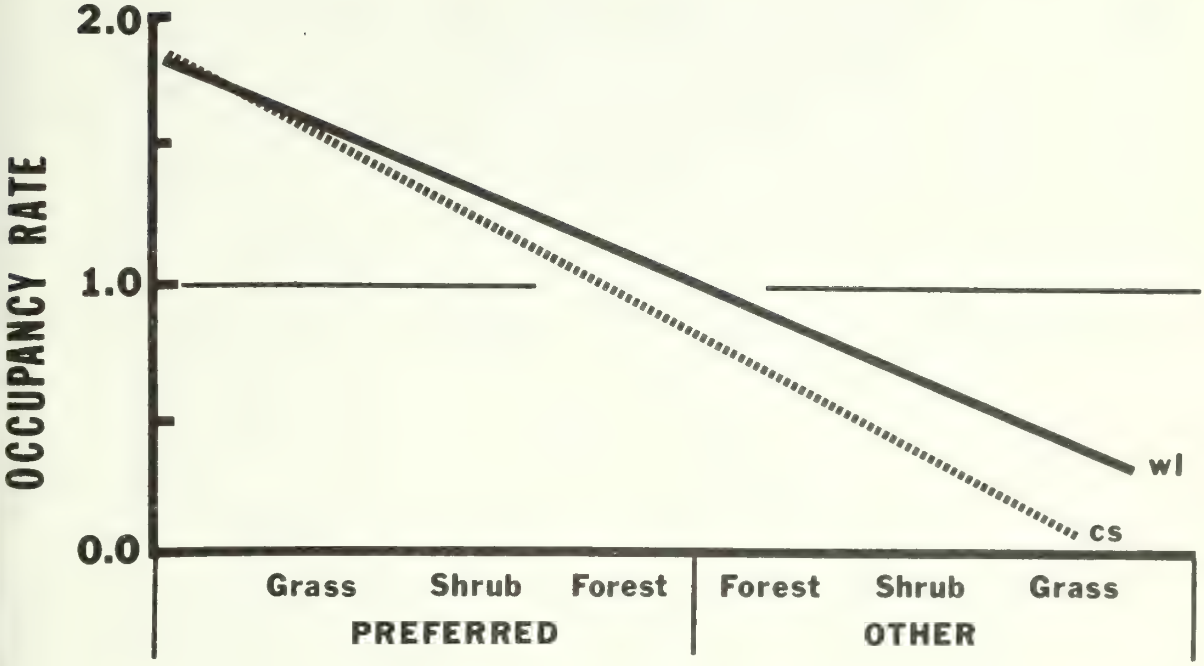

Figure 9. Juniper (forest) essentially provides cover for mule deer; woodland communities containing preferred forages and those lacking such forages were occupied at equivalent rates. Preferred shrubland and grassland communities contained important forages and were occupied at higher rates. Results were similar on the Chase Spring (CS) and Ward Lake (WL) winter ranges.

Deer forage-cover relationships of western juniper communities

Juniper stands constitute the sole woodland type over much of central Oregon; therefore, they offer the only forest-like structural features. Although there is a great variety of plant species within juniper communities, forage diversity is low during the time of deer occupancy.

Forage. Diversity of juniper communities provides some diversity of forage, and forage diversity is required to meet the needs of deer in all seasons. Varying age, height, density, etc. of juniper creates different microclimates favoring some plants over others; thus, their presence depends partly on juniper itself. Many species, such as Sandberg bluegrass (*Poa sandbergii*), are deer forages which persist in otherwise harsh sites due to the juniper's ameliorating effect on the microclimate.

Normally considered to be browsers, deer are in fact opportunistic with respect to food habits (Kufeld et al. 1973). In order to survive

at a viable level of productivity, deer must eat the best they can find under prevailing conditions (Figure 10). Deer do show preference, however, for some species and subspecies of browse, grasses, and forbs. Preferences change according to phenological age of plants. Deer select those stages which are rapidly growing and highly digestible. Standard analyses show that such stages contain most nutrients in balanced amounts (Subcommittee on Feed Composition 1969). Availability limits choices, yet deer tend to eat species at those stages which meet or exceed current requirements. Consequently, forbs, such as cinquefoil (Potentilla newberryi), are important during a mild winter so long as they are available (Figure 11), but less preferred browses, such as big sagebrush (Artemisia tridentata) and rabbitbrush (Chrysothamnus), are used of necessity during severe winter weather (Figure 12).

Ruminants in general consume great quantities of highly digestible forage when it is available (Figure 13). One of the keys to plant-use

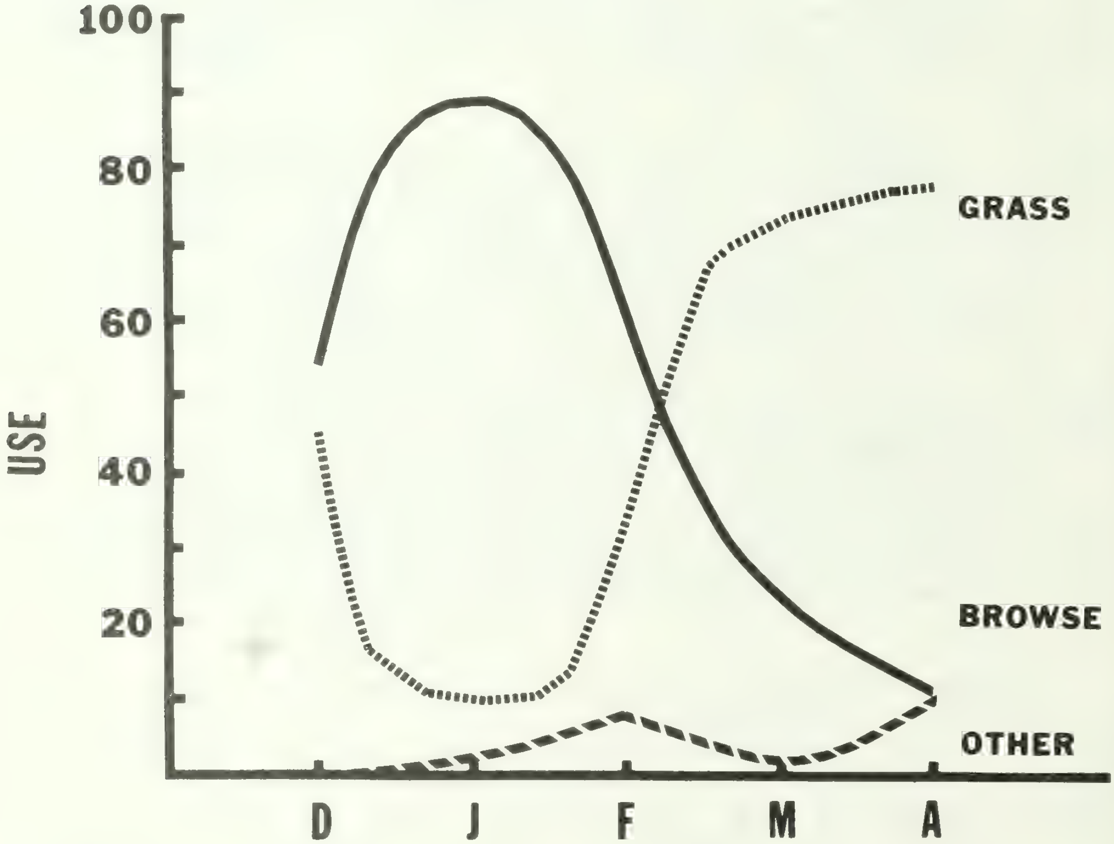

Figure 10. Mule deer are opportunistic foragers. They concentrate on the most digestible foods that are available. Browsing occurs predominantly when grass and forb herbage is cured or when their new growth is covered with snow (use is relative frequency).

FEEDING OBSERVATIONS
WARD LAKE 1967-68

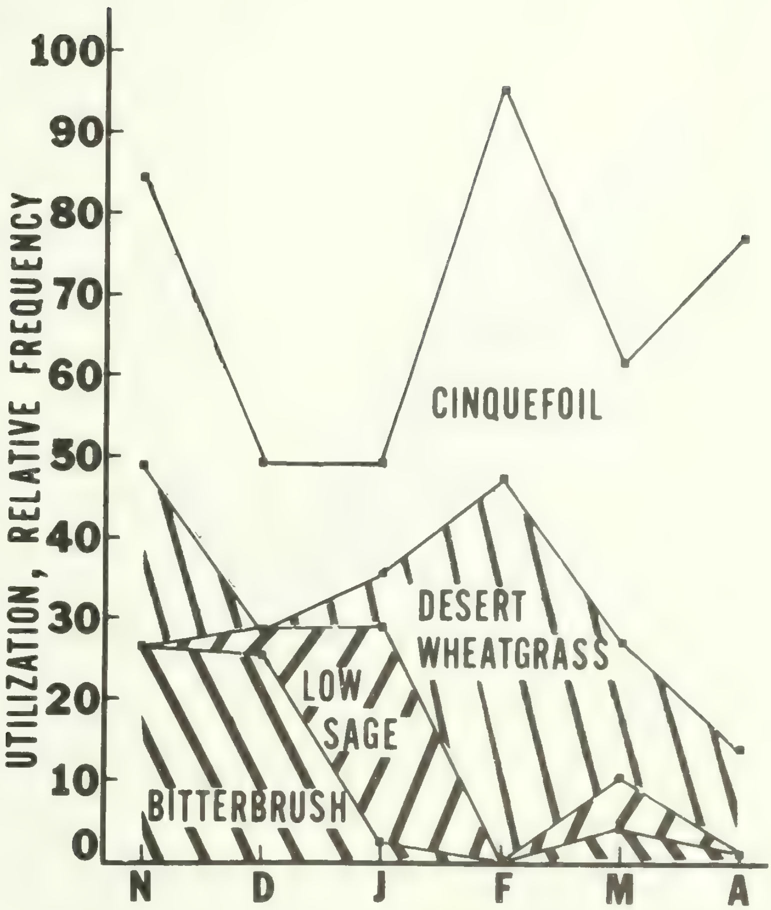

Figure 11. Mule deer usually fed on the highly digestible, growing herbage of forbs and grasses during the mild, snow-free winter of 1967-1968. Browse was unimportant after January. (Plant names: bitterbrush, Purshia tridentata; cinquefoil, Potentialla newberryi; desert wheatgrass, Agropyron cristatum, A. pectiniforme, A. sibiricum; low sage, Artemisia arbuscula).

FEEDING OBSERVATIONS
WARD LAKE 1968-69

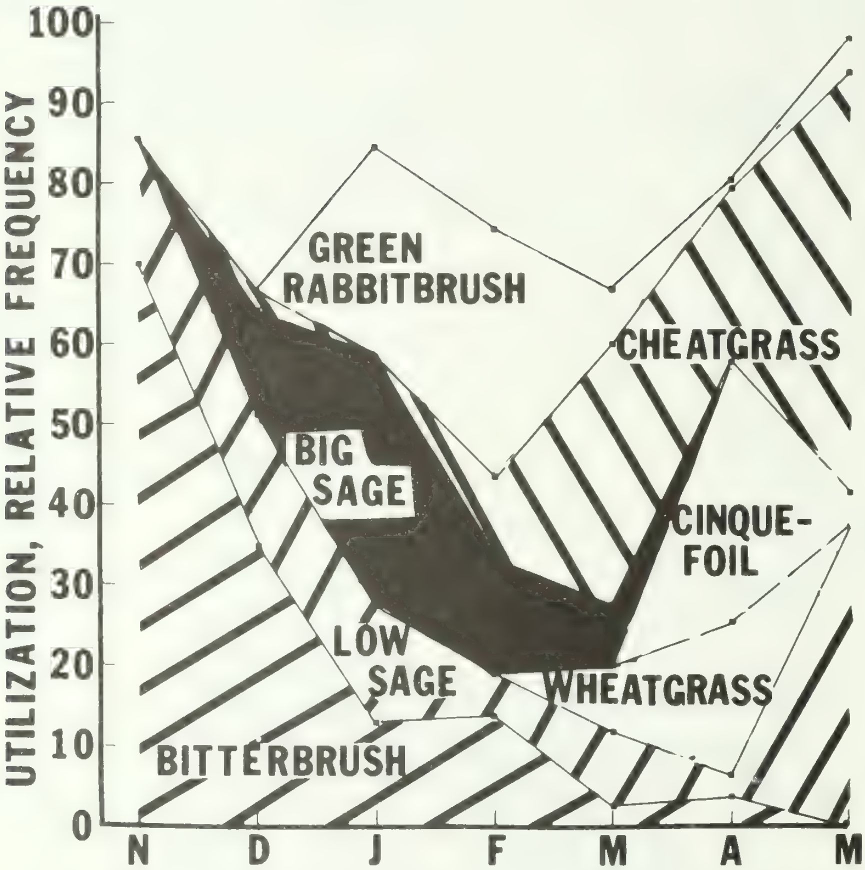

Figure 12. Mule deer usually fed on poorly digestible but available shrubs during the severe, persistently-snowy winter of 1968-1969. Forbs and grass became important only after the snow melted in March. (Plant names: big sage, _Artemisia tridentata_; bitter-brush, _Purshia tridentata_; cheatgrass, _Bromus tectorum_; cinquefoil, _Potentialla newberryi_; green rabbitbrush, _Chrysothamnus viscidiflorus_; low sage, _Artemisia arbuscula_; wheatgrass, _Agropyron cristantum_, _A. pectiniforme_, _A. sibiricum_).

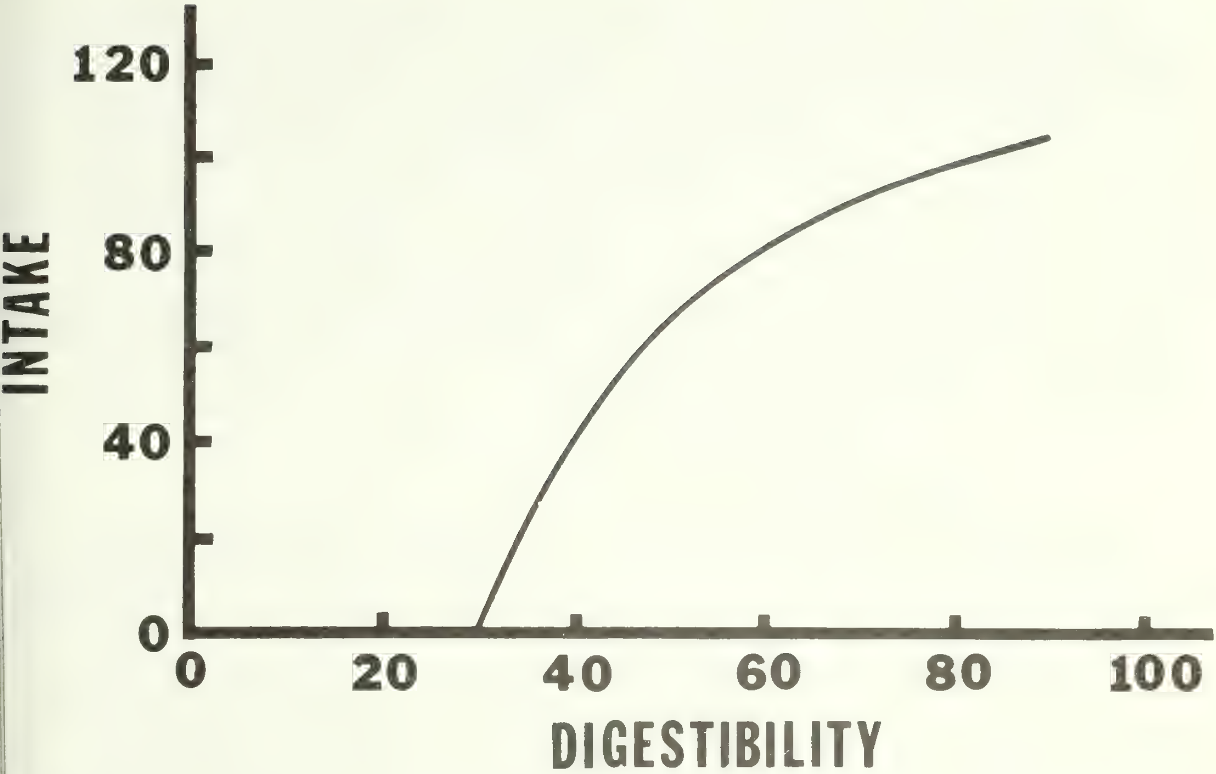

Figure 13. Ruminants generally and mule deer specifically can eat more per day as forage quality improves because food is digested faster and residues travel more quickly through the system. Digestibility of browse averages under 50 percent while that of young grasses and forbs averages over 60 percent.

appears to be digestibility (quality) (Ammann et al. 1973). Deer may even gain weight during a mild winter when grasses and forbs are available and digestibility of the diet may be as high as 80 percent. However, digestibility of browse is about 50 percent; so if conditions are sufficiently stressing, the energy in browse can not be obtained quickly enough to meet the animal's needs. The volume of a deer's rumen in fact becomes limiting. For example, deer consuming bitterbrush may still lose weight because they must draw on body reserves to offset energy losses. Juniper is nutritionally as good as other browse such as bitterbrush and low sagebrush, but in our study it was used less frequently. Juniper is essentially an emergency forage which often is not sufficiently digestible to meet deer needs, but at the same time it may be all that is available. Foraging on juniper occurs primarily during weather stress as attested by many examples of extreme use.

Cover. Cover value can be predicted because the microclimate varies with vegetation height, crown closure, crown depth, stem size, and stem density (Bergen 1971, 1974; Cochran 1969; Gary 1974; Geiger 1966; Gifford 1973; Reifsnyder and Lull 1965). Cover is valuable to deer because it helps reduce energy losses. A specific example of structural qualities of one juniper stand in which we monitored weather severity were as follows: 1) average height about 4.5 meters (15 feet), 2) 25 to 30 percent crown closure, 3) crown depth near 3 meters (10 feet), 4) density of about 33 stems per hectare (80 per acre), and 5) a juniper/big sagebrush-bitterbrush (Purshia tridentata)/bluebunch wheatgrass (Agropyron spicatum) community. These stand conditions created a microclimate that was 40 percent less severe than that in the adjacent shrubland (Bright 1976; Leckenby and Adams, in manuscript) and provided essential thermal cover for deer by moderating intensity and duration of weather severity.

MANAGEMENT OF WESTERN JUNIPER FOR MULE DEER

Management of western juniper communities can preserve the system as well as provide for needs of mule deer. Diversity of plant communities and successional stages can be preserved or enhanced if the interrelationships are accounted for in planning.

Winter and summer ranges require different management plans. On winter range, thermal cover is vital for deer to survive temperature extremes, but hiding cover is not as important. Exposure and movement cost more energy than animals can afford; therefore, diversity and interspersion of forage and thermal cover are critical (Malecheck and Smith 1976; Moen 1976). On summer range, thermal cover is essential for optimum reserve storage and protection from heat stress (Brody 1956); hiding cover, on the other hand, is an important buffer during fawn rearing and hunting seasons.

Prescription

How should western juniper communities be treated to effectively benefit mule deer? If information suggests treatment is necessary, no more than 1/3 of each vegetation stand should be altered until more specific knowledge is available. Created openings should average between 5 and 10 tree heights in width, but none should exceed 120 meters (400 feet). Known high-use thermal cover, hiding cover, and travel ways should be maintained. Overall, we should manage for about 40 percent of the basic management unit in cover and 60 percent in forage areas (Thomas et al. 1976).

Management for small openings is more likely to present a net gain of energy to the subpopulation, because forage can be increased with only minimal loss of cover--the best of two worlds. Weather severity is greater in shrub or grass dominated clearings within juniper stands than in the woodland itself. Wind, heat radiation, and other effects increase proportionately with width of openings (Bergen 1972; Cochran 1969; Geiger

1966; Gifford 1973). Furthermore, height of vegetation adjacent to a clearing and weather severity are inversely correlated within a narrow band from the edge toward the center of an opening. The relative values of thermal cover and forage areas in each situation must be carefully weighed when management decisions are made.

Prescription tips

Under multiple-use concepts, juniper has positive aspects, but some management is justified for increasing particular products. Some of the following management tips may be helpful:

1) The management plan for each project should coordinate use of all resources over time (grazing, wood cutting, etc.).

2) If treatment appears necessary, it should be planned according to knowledge of values, animal-plant community interrelationships, and the predictibility of results.

3) Treatment areas should be selected on the basis of sound knowledge of the area and demonstrated need. We can not afford to manipulate in desperation as if there were no tomorrow.

4) Various treatment methods should be tested and adapted to the plant community as well as to project objectives.

5) Techniques should be adapted to insure aesthetically acceptable treatments. Public sentiment definitely affects programs.

6) Fire should be used as a tool in itself or to supplement other techniques.

7) Replacement of a juniper monoculture with another monoculture, e.g. crested wheatgrass, should be avoided.

8) To operate in the most economical manner, forage should be planted in such a way that it is totally available to the deer.

9) Native forages should be considered to augment diversity. These should be easier to establish than exotics.

10) Results of each project should be objectively evaluated in terms of goals, accomplishments, failures, and total resource consequences.

11) Criteria other than minimal cost per acre should be used to measure treatment success.

RESEARCH NEEDS

To approach multiple-use management of the western juniper ecosystem, we need to simultaneously consider the multitude of products and the many interdependencies which constitute the system. Most facets of this ecosystem are, at best, vaguely perceived. Future research then should address the following:

1) Interrelationships of animal and plant communities need to be considered in total perspective with management of the ecosystem, management of featured species, and needs of society over time.

2) A simple system is needed to help us objectively evaluate goals and objectives for overall management of western juniper communities.

3) The consequences of management alternatives with respect to all wildlife should be investigated and publicized.

4) Our files of descriptions of and keys to natural and induced juniper communities should be expanded so managers will have the necessary tools to identify site potentials within each project area.

5) Juniper communities should be mapped and measured so land-use planners have the data required to coordinate resource uses in time and space.

6) The successional stages produced by each treatment of each community need to be described. Longevity of a stage is obviously important to the management time frame.

7) Predictibility of response of the various treatment-community combinations should be quantified.

8) Economic values and tradeoffs of alternate methods should be compared. Appropriate economic measures of success which reflect total cost to society are needed.

CONCLUSIONS

Our responsibility as custodians of the western juniper ecosystem includes an obligation to future generations. They cannot afford our ignorant and desperate attempts to fulfill short-term, single-use goals. By retaining management options for future generations, we can gain the flexibility we seek today. Management founded on guiding theory and evaluated by deciding experiment should progress toward fulfillment of that responsibility.

Predictibility will increase if we use the integrating factors of plant community structure for cover management over broad areas and

community composition for forage management on local ranges.

Behavior and physiology suggest a requirement for habitat diversity within mule deer subpopulation ranges. Plant community diversity, structural and compositional, met varying seasonal requirements of mule deer; such diversity provided insurance against the vagaries of weather within and between years.

Preservation of habitat diversity for deer will not satisfy our obligation to future generations. Mule deer are only one product of the western juniper ecosystem.

ACKNOWLEDGEMENT

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EFFECTS OF WESTERN JUNIPER ON FORAGE PRODUCTION AND LIVESTOCK GRAZING MANAGEMENT

Thomas E. Bedell, Extension Rangeland Resources Specialist
Oregon State University, Corvallis

Thomas R. Bunch, County Extension Agent
Oregon State University, Prineville

ABSTRACT

Western juniper has a serious effect on livestock production. Unless checked by effective control and subsequent management measures, forage production on sites containing seral stands of juniper will continue to decline regardless of grazing management. Beef cattle stocking rates have increased from 50 to 300 percent from juniper removal alone. Coupled with seeding and improved grazing management, juniper control has changed production from 15-20 acres per AUM to 3 acres or less per AUM.

Keywords: Livestock forage, forage production, livestock management

What effect does a particular population of western juniper (*Juniperus occidentalis* subsp. *occidentalis*) have on the ability of a site to produce usable range forage? If the answer to this question were known with certainty there would be no need for a presentation on this subject. Our conclusions after several somewhat frustrating hours of investigation left us little better off than at the beginning. We did conclude, however, that western juniper has a serious effect on livestock production. Effective preventive measures, if not taken when populations are small and trees young, commits a site to continued and increasingly lower forage production.

Several investigators have described sites or habitat types in which juniper is an important component (Eckert 1957; Driscoll 1964; Soil Conservation Service 1967, 1969, 1970; Burkhardt and Tisdale 1969; Hall 1973). Only the Soil Conservation Service and Hall publications provide any herbage production or stocking rate data. Difficulty exists in knowing whether such data were derived from climax or seral juniper stands.

Although juniper has been controlled by a variety of techniques throughout its ecological range with varying degrees of success, there are virtually no published studies on the effects of western juniper control on subsequent forage production and composition. Evidently the responses obtained were sufficient to justify control efforts.

Juniper is no respector of range condition. Burkhardt and Tisdale (1976) made studies which indicated that little or no repressive effect on juniper seedlings could be attributed to herbaceous competition. From this and numerous personal observations, we cannot expect grazing management alone either to keep out juniper seedlings, or if seedlings are present, to suppress their growth and influence on associated vegetation. Burkhardt and Tisdale also observed that there was better juniper seedling establishment on deep, less well-drained bottom sites but a higher growth rate on the upper slopes with well-drained soil.

No doubt juniper will not invade extremely arid range sites, but where it already exists, most observers agree that its influence is increasing. From a livestock-forage management standpoint, arresting the increase shortly after it has invaded and before range condition and/or forage production declines significantly, should be more economical and effective in the long run.

Juniper trees can provide desirable winter habitat for cattle and sheep and are especially beneficial during calving or lambing for physical protection. Conversely, during hot weather, protective shade is provided. Most other effects would probably be judged harmful for forage production and livestock management, at least by the livestock owner or manager.

Juniper competes for moisture and nutrients and, in effect, contributes to a more arid environment. Erosion hazard increases as a larger percentage of the soil surface becomes bare. Shade directly beneath the canopy sometimes results in more herbage than around the periphery of the tree. This may be due to lower evaporation and transpiration coupled with protection from grazing livestock by the lower branches.

In the central Blue Mountains of Oregon, Hall (1973) described four juniper (more than two trees per acre) plant community types and reported herbage production from sites in good range condition. About 350 pounds air dry herbage per acre was produced annually from the juniper-bunchgrass community type and about 400 pounds from the juniper-big sagebrush (*Artemisia tridentata*) type.

Both of these vegetation community types could be successfully seeded. The other two types are juniper-stiff sagebrush (Artemisia rigida) scabland with about 200 pounds per acre and juniper-low sagebrush (Artemisia arbuscula) with about 400 pounds per acre. Successful reseeding on the latter two types is questionable. In 1976 on a site with 12-20 trees per acre at the Squaw Butte Experiment Range in Harney County, Britton (1977) recorded 150 pounds of oven dry grass and forbs per acre. Range condition was estimated to be in the high fair category.

If one assumes that 50 percent of the herbage should remain after grazing to maintain the plant community then the stocking rates would be 3-3/4, 4-1/4, 3-3/4 and 7-1/2 acres per animal unit month (AUM) for the juniper-big sagebrush, juniper-bunchgrass, juniper-low sagebrush and juniper-stiff sagebrush types, respectively. These data correspond closely to Soil Conservation Service (1967) estimates of 3-7 acres per AUM for a juniper south exposure site in good condition and Burkhardt (1977) in southwestern Idaho. At Squaw Butte, 10 acres of fair condition range would be needed per AUM based on Britton's measurements.

As juniper trees become more dense, forage production declines. Because livestock numbers are often not balanced to the declining amount of available forage, range condition may decline at an accelerated rate. Consequently, many areas with thick stands of juniper do not have sufficient populations of desirable perennial species to respond if juniper competition were removed. Seeding after juniper removal is suggested when this described situation occurs. The degree of success will be limited by site characteristics.

For the livestock owner, juniper control must result in measurable management benefit. Most improvements show up in higher stocking rates regardless of the kind and class of livestock. Interviews with central Oregon cattle ranchers indicate from 50 percent to 300 percent improvement in stocking rates from juniper removal alone. One stockman indicated a four-fold improvement in grazing capacity when all of the juniper was removed and part seeded to crested wheatgrass. Depending upon the site, up to 3 acres per AUM stocking rates have been achieved with juniper removal and good grazing management alone. From 4-5 acres per AUM would probably be more common.

Areas of high site potential but with sparse understory and dense trees respond well to drilling of crested wheatgrass (Agropyron desertorum) following juniper removal. Areas with practically no available forage, producing at 15-20 acres per AUM, commonly are improved to a stocking level of 3 acres or less per AUM with crested wheatgrass or other appropriately adapted species.

Soil disturbance, even if not seeded, can be beneficial. One rancher observed that cheatgrass (Bromus tectorum) was 6 to 8 inches tall where juniper was removed by a bulldozer but only 1 inch tall in the undisturbed area.

Forage utilization under trees has been noted by several observers. Idaho fescue (Festuca idahoensis) is often left ungrazed under a juniper canopy, yet when juniper is removed it is readily grazed. Dealy (1972) noted the same phenomenon with ponderosa pine (Pinus ponderosa). He attributed it to a buildup of pine duff and continual carryover of fescue litter. Something similar may contribute to poor fescue utilization under juniper.

It is not uncommon for juniper ranges to contain an almost sod-like cover of Sandberg's bluegrass (Poa secunda). Removal of juniper competition will not result in improved forage production. Seeding is necessary but will not be successful until bluegrass competition is controlled through cultivation or an appropriate herbicide. Once established, crested wheatgrass will out-compete many other species and the stand can remain productive for years. Ranchers observe that juniper invasion is suppressed more by crested wheatgrass than native grasses.

The degree of improvement in a range-livestock operation largely depends upon the managerial skill of the operator. More forage may result but such forage must be efficiently and effectively converted into livestock output to be economical. Range improvements should improve grazing capacity of the area treated and the entire ranching unit if properly managed. Improved individual animal performance may occur. Better nutrition coupled with appropriate livestock husbandry should result in higher percent of conception and subsequent calving percentage. Often the improved grazing capacity will mean that fewer males per 100 females are necessary. This could translate into the purchase of higher quality males and thus greater and more rapid herd improvement than without range improvement.

SUMMARY

Although many thousands of acres of western juniper have been controlled through a number of procedures throughout the large juniper zone from northern California to southern Washington, no forage production response research preceded or accompanied this control effort. There is no doubt that substantial forage increases occur on favorable sites when juniper and associated shrub species are controlled and appropriate followup procedures carried out. Often, little or no forage increases are observed where juniper on rocky and shallow soil sites is controlled.

We recommend that quantitative guidelines be developed whereby forage production changes can be accurately predicted site by site. This will involve some additional research but sufficient juniper removal projects have occurred and will occur so that accurate information can be developed. As an example, in the Grant County area some of this kind of information should come out of the Oregon Range Validation Project.

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PHYSICAL PROPERTIES AND COMMERCIAL USES OF WESTERN JUNIPER

John R. Herbst, Area Extension Forester
Union County Extension Service
La Grande, Oregon

ABSTRACT

Western juniper (Juniperus occidentalis Hook.) has several properties which could be commercially marketed. Historically, western juniper has been used for fenceposts, decorative boughs, and firewood. Volatile and essential oils can be extracted from foliage and terminal branches as well as from the wood of western juniper. These oils are valued as flavoring and scenting agents. Presently the wood is being used for making furniture as well as paneling. The wood can be successfully dried, cured and made into products. The wood of juniper has a very attractive smooth finish with pleasing coloration and aroma. Veneer, hardboard and particleboard have all been successfully manufactured from juniper.

Keywords: Juniper, properties, oils, wood, lumber, utilization.

INTRODUCTION

The intent of this paper is to present information on the physical properties of western juniper (Juniperus occidentalis Hook.) as well as some of its properties which limit its commercial usefulness. The paper was going to be fashioned around future potential commercial uses of western juniper. However, the crystal ball is out of order and "future" implies that there are no present commercial uses of juniper. Presently, there are no large concentrated markets for western juniper. Like any other material or product which is marginal, these markets need to be developed. Will there be markets for windfall gains for those whose lands are overtaken by western juniper? Not likely! There are many costs involved with harvest and manufacture of juniper which negate the likelihood that it will be a valuable species on the stump in the near future.

HISTORIC PRODUCTS

Some of the historic products for which western juniper has been used are: fenceposts, decorative boughs, and firewood. Within western juniper's range it is touted as a fencepost. According to results from Oregon State University's post farm (Miller and Graham 1971), western juniper posts have lasted as long as 40 years in western Oregon's damp climate. The average life of posts which had decayed by that time was 22 years. This indicates an exceptionally good service life, especially when compared to lodgepole and ponderosa pine in the same area which have an untreated service life of between 3 to 6 years. It should be noted however, that the post farm was set up in 1927 and the posts used contained a high percentage of heartwood. Today, many juniper posts are being used that are largely sapwood. Untreated, these have no more decay resistance than lodgepole pine.

Western juniper is a good fuel wood, burning clean with little smoke and ash. One complaint is that in windy desert areas the shaggy bark tends to pick up wind blown sand and debris, therefore dulling chainsaws more rapidly than other fuel woods. In protected areas this is no problem. Decorative boughs are marketed every year around Christmas time.

INSECTS AND DISEASE OF WESTERN JUNIPER

Western juniper is commonly host to two mistletoes. They are dense mistletoe (*Phoradendron densom* Torr.), and constricted mistletoe (*P. ligatum* Trel.). While the mistletoe may sometimes cause witches'-broom, there are at least two rusts attacking western juniper that also commonly cause witches'-broom. These are *Gymnosporangium kernidium* (Bethel) and *G. betheli* (Kern).

There are at least two rots which commonly attack western juniper, sometimes rendering the wood unsuitable for any product. These are juniper pocket rot (*Fomes juniperinus* V. Schr.), a white pocket rot, and a brown cubicle rot usually found in the basal portions of the trunk. The pocket rot generally will extend farther up the tree than will the brown cubicle rot. A few feet of "long butting" will often get rid of the brown cubicle rot. Some trees which have been affected for long periods of time are hollow for most of their length. In some trees both rots occur and other times they appear singularly.

A longhorned wood borer (*Callidium californicum* Casey) attacks western juniper; the larvae bore into wood, both wet and dry. Kiln drying kills the larvae of this roundheaded borer, but if material is air dried, the insect will eventually work its way out. There are also some flatheaded borers which occasionally attack western juniper.

PHYSICAL PROPERTIES

Oils

Fahey and Kurth (1955) completed a chemical analysis of the volatile oils from the foliage and terminal branches of western juniper in 1953. They found that the volatile oils included the following: α-pinene, β-phellandrene, dipentene, ρ-cymene, sabinene, terpinolene, α-terpinene, terpinen, δ-borneol, borneolacetate, cadinene, acetic acid, phenols, and traces of aldeydes.

In 1972 and 1973, the Four Corners Regional Commission funded a juniper oil demonstration project (1973). This project was an economic pilot project to produce essential oils from Juniperus osteosperma (Torr.) and J. scopulorm (Sarg.). Professor Walter H. Johnson of Utah State University isolated essential oils from these species in 1964. The essential oils are valued as a flavoring or scenting agent in soaps, aerosols, insecticides, beverages, medicines, and many other products. The volatile oils from western juniper are quite similar to the volatile oils that were collect from Juniperus osteosperma and J. scopulorum. There are markets for these oils.

Kurth and Ross (1954) extracted essential oils from western juniper wood in 1954. Entire trunks and bark were used in this experiment. The major oil derived was cedrol. At that time adequate amounts of cedrol could be extracted from juniper wood to make an economic process, but western juniper cedrol contains an oily odor which is not desirable for scenting or flavoring. The investigators however, obtained crystalized cedrol with a pleasant odor by using low steam pressures. The investigators commented that the oily odor could probably be removed from cedrol obtained under higher pressure to make it competitive in the essential oil market. A substantial increase in total amounts of oil recovered occurred under higher pressures.

Lumber

Logs coming into the mill are rough with rapid taper and short lengths. Most of the logs are extremely limby except those grown on better sites among ponderosa pine and Douglas-fir. On most sites bark inclusions go deep into the wood. The logs have insect and disease problems along with nails, lead, wire, and the like.

Juniper has a reputation of warping and twisting when drying, being difficult to plane smooth, and for splitting. It does not deserve this reputation. The wood has been air dried by entrepreneurs for making furniture and novelty products for many years. The wood, especially if cut into fairly thin boards, kiln dries very well. Kozlik (1976) reports on kiln drying schedules for western juniper. Besides kiln drying, any slow drying process appears to work quite well for juniper.

During 1973 and 1974, Gary Johnson, State Service Forester, and the author attempted air drying by several methods with varying results. Rough lumber in 1-inch, 2-inch, and 4-inch stock was dried. The methods of drying were principally a slow, even drying process through different means (Brown 1976). One sample included juniper wrapped in a tarp and hung in a shed where air drying wouldn't remove moisture too rapidly. Other methods of air drying included storing under a dry building and curing in dry sawdust. Drying resulted in little warp or checking in the 1-inch boards. In the 2-inch and 4-inch boards, cracking and splitting was substantial except in the sample wrapped in a tarp. One craftsman recommends drying on end in the shade out of the breeze. Drying juniper properly is no mystery. Craftsmen who suggested these techniques were mostly from central Oregon and include Ralph Bailey and T. D. Sexton of Bend and Bill Koi of Sisters.

Finishing sawn products causes some difficulty. Juniper grain continually picks up when planed. Gary Gumpert of Juniper Products, Inc. in Prineville solved this problem by using abrasive planers, essentially a series of industrial sanders, to obtain a satisfactory finish. While abrasive planing is not commonly used in this area, it is not, by any means, a new method used in the wood products industry.

The color of the wood can vary a great deal. The most common colors found are a strikingly white sapwood with heartwood which varies from a light yellow to a yellowish orange and rarely almost red. In some areas individual trees may be close to red, some close to black and some may be greasy in composition. The wood has a pleasant aromatic quality but it is not as aromatic as many members of the cedar family. If the aroma fades over time, it can be revived by sanding.

Veneer

Juniper can be either turned or sliced to obtain a high quality facing product for plywood. Barger and Ffolliott (1972) report on physical characteristics of some juniper species in New Mexico and Arizona stated that veneer turned or sliced makes an attractive product. The Edward Hines veneer mill in Mt. Vernon, Oregon, rotary cut some juniper veneer. The Edward Hines Plywood plant at Hines, Oregon dried and glued the veneer. The lathe was set for cutting Douglas-fir at three-sixteenths of an inch. Consequently, there was some cracking and splitting of veneer which would not take place if the bolts were either steamed before turning or the lathe pressure changed slightly. Mr. Asher, Manager of the Plywood Plant, was of the opinion that there would be no difficulty in successfully turning juniper.

Manufactured Boards

Frashour and Nixon (1956) of the Oregon Forest Research Laboratory in Corvallis produced some hardboard from extracted juniper chips. The juniper chips were the ones from which Kurth and Ross had extracted essential oils. The hardboard obtained possessed superior bending strength and water resistance but did not have toughness properties that some other western species have. An advantage to using juniper as hardboard was the uniformly colored and semi-glossy finish obtained without the use of water spray. Frashour and Nixon indicated that the inferior toughness could probably be traced to the extended chip steaming in order to obtain volatile oils.

A technical action panel of Wheeler County headed by Mr. Hubert Asher of Spray looked into the feasibility of producing particleboard from whole juniper trees. This project took place in the period of 1964 to 1966. The results of the study reported by Ray Currier, Oregon Forest Research Laboratory, were that the particleboard could easily be formed and did possess aromatic qualities. At that time the amount of material available as residue for mills for particleboard outcompeted the harvesting of juniper for this type of product.

COMMERCIAL USES OF JUNIPER

The Forest Products Laboratory at Madison, Wisconsin, conducted a brainstorming session on utilization of juniper and developed the following ideas: toys, sporting goods, compost, jewelry boxes, chicken feed to make gin flavored eggs, block flooring, patio flooring, stems for plastic trees, condiment for cooking, wildlife feed, suitcase liners, humidors, pipe bowls from roots, furniture, decorative fences, planters, inlay products, paneling, Christmas decorations, novelties, closet liners, additive for men's cosmetics, volatiles, flavoring, bedding from shavings, condiment for cooking game from berries, and signs. The California Division of Forestry has shipped some logs to Japan which were peeled and finished by sanding to a high gloss and used as exposed interior studs. The extent of this type of market is unknown. There has been interest expressed by an eastern cedarchest manufacturer in using juniper for chests.

What are some of the more feasible juniper products? Aromatic oils may be a possible market. Western juniper oils may need some refining before they are competitive with oils from eastern redcedar (*Juniperus virginiana* L.) and Mexican juniper (*J. ashei* Bucholz). The pilot plant in Blanding, Utah was successful in extracting volatile oils which were saleable. However, the company formed to take over the pilot project on a full scale basis never did that. This does not mean that is is not economically feasible. More times than not, pilot projects of this sort are not followed up even though they prove out to be economically feasible.

Juniper Products, Inc., in Prineville is manufacturing a three-eighths inch tongue and groove sawn paneling for use on both walls and closets. Presently their product is being sold in Washington, Oregon and California. This is a family operation, and consequently they are not selling large quantities. Some marketing research has shown that there is a market for the product if there were enough suppliers to produce it in larger quantities.

Another product being manufactured by Juniper Products, Inc., and other craftmen in the area is furniture. The easy workability, good color, and fine finish of juniper makes it an excellent furniture wood. In fact, it is in the same genera as the eastern redcedar used for cedarchests and other fine furniture and closet liners. The aromatic qualities are not as good as eastern redcedar, but they are nonetheless present.

Juniper's fine finishing qualities also lend it to veneer manufacture. The veneer could be manufactured either by rotary lathe or by slicer. Total recovery in this process, as in sawing, would not be high. Expected recovery rates would be in the 40 to 60 percent range.

It is feasible to manufacture aromatic particleboard from juniper using the total tree. However, until particleboard plants run out of residue materials from mills which produce other wood products, it is not likely that juniper will be used for this process.

The wood of juniper makes excellent wood pencils. One of the difficulties in manufacturing this product is attempting to find enough clear stock without knots with straight grain from which to make the pencils. The wood apparently has excellent qualities as far as wood pencils are concerned.

Another small continuing market that is always available is for decorative boughs. Around Christmas time buyers are always around juniper areas buying boughs that are well laden with berries for use in the Christmas market.

Other product possibilities for smaller markets are the novelty products which are already being produced over quite an extensive area as well as fenceposts and even charcoal.

MARKET POTENTIAL

The technology is available to make products from juniper. Juniper is not an impossible wood with which to work. It is economical to make products from juniper. There is a branch of economics that will have to be dealt with before many people start manufacturing juniper. This is market research and development. The market research and

development done by Juniper Products, Inc., for instance, in manufacturing of paneling and furniture indicates that there are people desiring to purchase substantial amounts of products made from juniper at present prices.

Logging and handling of juniper is an expensive process and recovery rates are low. However, the cost of handling and manufacturing are not the criteria which define whether a product is economic to market. The important criterion is whether the value of the product is able to cover those costs plus the needed profit margin.

Before many years there likely will be a substantial market for juniper products. Historically, it takes 5 to 10 years following an innovator and entrepreneur who opens the market for a product before the product really sells. Because Juniper Products, Inc., started operating in 1974, I would predict that by 1984 there will be a fair sized market for juniper products. A curious thing about these types of markets is that Juniper Products, Inc., quite likely will not be one of those supplying this market. New, more conventional manufacturers will probably supply the market. The market for juniper products will develop faster if and when a good housing boom occurs, or if there is an upswing in the economy of either the United States or Japan.

MANAGEMENT IMPLICATIONS

One of the reasons for giving this paper is an attempt to set some management criteria for juniper, especially if it is going to be looked at from a products standpoint. The management implications for juniper products would vary depending on the product for which you are trying to manage. For instance, if boards and veneer are the desired product, it would be best to manage juniper on the moister end of its range, although not necessarily in deep soil. A straighter, taller tree with fewer small branches and not as much bark inclusion seems to be produced where juniper grows in mixed stands with other forest trees. Quite often the heartwood is a deeper color which gives better grain contrast as far as these products are concerned.

If juniper is to be managed for lumber or veneer products, insects and diseases would need some control. Both the longhorned wood borer and the pocket rots and brown cubicle rot are problem areas.

If management is for production of oils, juniper on open grown or invasion-of-rangeland conditions may be the best. These junipers tend to produce many branches and needles from which more essential oils can be extracted. Branches and needles tend to give more of the aromatic flavor that may be desired in a particleboard product.

Unless the market for juniper products becomes much larger and much more stable than predicted from present conditions, juniper stands should not be managed for a product. Instead management might include eradication methods while riding on the novelty of juniper markets. This way the wood will be utilized and perhaps the cost of range rehabilitation will be decreased.

RESEARCH NEEDS

Research needs mentioned here are in regards to products made from juniper. These needs certainly are not listed in order of importance as the importance will depend somewhat on the eventual development of markets.

1. Insect and disease incidence.
2. Influence of environmental factors on quality of product.
3. Veneer slicing. Contact with one veneer slicing mill found them reluctant to try slicing juniper. They did not think there was a large enough supply to keep them going in this market.
4. Marketing of products. As indicated earlier in this paper, this may be the most important research need at this time.
5. Research on the modification of the properties of cedarwood oils from western juniper. This would make them more competitive with oils from other junipers.
6. Product research to find uses for western juniper oil in its natural condition.
7. Inventory of amount and quality of juniper. This would be necessary information for market development.

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PUBLIC PARTICIPATION IN WILDERNESS AND BACKCOUNTRY LITTER CONTROL:

A Review of Research and Management Experience

Robert M. Muth | Roger N. Clark

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service
Portland, Oregon

Contents

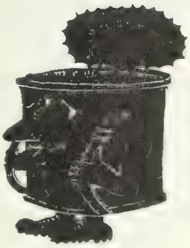
Abstract

This paper describes the application of the Incentive System for Litter Control to wilderness and backcountry environments. Based on research, observation, and management experience, a set of procedures was developed and is presented here. Additional management considerations are discussed.

Keywords: Litter (refuse), wilderness management, recreation use (-forest damage, public involvement.

Authors

The authors are cooperative research associate, College of Forest Resources, University of Washington, Seattle, and Project Leader, Recreation Research Project, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Seattle, Washington.



Introduction

This paper is less a report of research findings than an effort to diffuse existing technology. The Incentive System for Litter Control was developed in the early 1970's by researchers at the Recreation Research Project as a litter control technique meant to supplement traditional means of litter control in public campgrounds and dispersed road recreation areas (Clark 1971; Clark, Burgess, and Hendee 1972; Clark, Hendee, and Burgess 1972). Although this system was devised for use in developed recreation areas, it also has potential for helping solve the litter problem in wilderness and backcountry environments.[1/]

The objective of the studies reported in this paper was to determine the applicability of the incentive approach to controling litter in roadless areas. Based on the results of these studies and managers' experience, a set of guidelines was developed. These guidelines and some of the insights we gained while testing them are reported in this paper.

THE INCENTIVE SYSTEM

The Incentive System for Litter Control is an approach that has proven effective in controlling litter in developed and dispersed-road recreation areas. Under the incentive approach, families and children are contacted by Rangers and asked to help pick up litter (Clark 1976). They receive educational rewards in return for their participation. The incentive approach was developed through an extensive program of research by the Recreation Research Project of the Pacific Northwest Forest and Range Experiment Station and is now being used on a variety of National Forests and by other public agencies in the United States and other countries. Subsequent research provided additional evidence that incentives are an effective tool for litter control in several kinds of locations (Kohlenberg and Phillips 1973; Powers, Osborne, and Anderson 1973).

The three primary objectives of the incentive system are: (1) to achieve more effective litter control than that accomplished by traditional methods; (2) to give the public a sense or participation and responsibility by involving them in litter pick up; and (3) to educate children and adults in anti-litter behavior which may be generalized to other recreational as well as non-recreational environments.

Application of the incentive system consists of six steps.[2/]

1. Campground Rangers (or Rangers on patrol in dispersed-roaded areas) first assess the litter problem. The Ranger may decide that the litter problem is so slight that it does not warrant treatment; the key is to use the program only when and where it is needed.

2. If there is a need to use the system, the Ranger then locates families who are camped in the area with children that might wish to be involved in the program.

3. The program is explained to the parents and children, and the Ranger requests the children's involvement. Usually children are eager to participate in helping the Ranger pick up litter. In return for

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[1/] For simplicity, we have used the word "wilderness" with a lower case "w" throughout the paper as an all-encompassing term which includes specific Wilderness areas, administratively designated backcountry areas, and other unroaded forest environments in which recreation use occurs.

[2/] A programmed slide-tape is available with further details on using the incentive system. It can be obtained by writing to Forestry Instructional Services, c/o Forestry Business Office, School of Forestry, Oregon State University, Corvallis, Oregon, 97331.

their help, he offers them a choice of incentives (from a variety of Forest Service Visitor Information Service items, e.g., Smokey Bear or Woodsy Owl shoulder patches, wooden rulers, Smokey Bear or Woodsy Owl bumper stickers, bookcovers, etc.).

4. The Ranger then organizes the children and gives them litterbags. What they are to pick up (perhaps concentrating on beverage-can pull tabs or cigarette filters), and what area they are to cover is described. The Ranger emphasizes that the litterbags need *not* be full, but that the area must be clean. The Ranger should stress that the objective is to clean up the area not just fill up litterbags. Arrangements are then made to meet the children at a certain time and place. They are cautioned about potential safety hazards, (broken glass, rushing creeks, etc.) and sent on their way.

5. Next, the Ranger returns to other duties such as campground maintenance, fire patrol, visitor contact, fee collection, etc.

6. Finally, the Ranger meets the children at the prearranged time and place, collects the litterbags, and gives out the incentives. The Ranger usually takes the opportunity at this time to talk with both children and parents about other problems of which they should be aware, such as fire danger or good outdoor manners.

THE NATURE OF THE WILDERNESS LITTER PROBLEM

Litter in wilderness environments presents special management problems. The esthetic objections against litter often seem stronger in these more natural settings than in other environments even though litter usually seems to occur in smaller amounts in unroaded environments. Studies of wilderness recreationists repeatedly indicate that litter, and other human-related debris, is perceived by users to be the most annoying problem encountered during backcountry experiences (Lime 1972, Solomon and Hansen 1972, Stankey 1973).

The cost of effectively coping with litter has lent impetus to finding new methods of achieving anti-litter behavior. One U.S. Forest Service effort, designed specifically to deal with the wilderness litter problem, is the Pack-It-Out Program which encourages recreationists to pack out their unburnable refuse. The Pack-It-Out Program has resulted in numerous benefits, including increased user participation, reduced litter levels, and reduced costs. But, despite widespread us of the Pack-It-Out Program, observation indicates that the litter problem is far from solved.

For a variety of reasons, many recreationists enter wilderness areas with little exposure to the Pack-It-Out message. Many times signboards are non-existent at trailheads or they have been defaced or torn down. With a small staff to cover large areas, only a few wilderness recreationists are contacted in the field. Where permits are required, some people receive them by mail, or only one or two people actually go into the Ranger Station while a majority of the party stays outside. Consequently, many recreationists enter wilderness without exposure to the message of the Pack-It-Out Program.

To control the wilderness litter problem, managers must take into account two characteristics of the wilderness litter problem which distinguish it from litter in other environments: limited access to the area and the dispersed nature of the use.

Access

Since trails are the primary means of access to wilderness areas, the Forest Service has traditionally relied on pack stock and wilderness Rangers for removing litter from roadless areas. Many hunting parties, using large pack strings, transport a substantial amount of equipment and supplies deep into the wilderness. And, although most horse users are conscientious about burning or packing out anything left over, empty cans, bottles, and cooking grates

are typical of what often gets left behind. In addition, litter often piles up at popular shelters, lookouts and other hiking destinations used exclusively by backpackers. Great difficulty is encountered in transporting these bulky, heavy objects or large amounts of litter out of areas which are not accessible by pickup truck and dumpster; especially in certain backcountry areas where traditional use has resulted in "garbage dumps" of amazing magnitude.

Dispersion

Although certain concentrations of litter exist, much of the litter which recreationists leave behind is widely dispersed over large areas. The dispersed nature of wilderness litter makes it an expensive and time-consuming problem to control especially if it is dispersed throughout little-used areas (remote wilderness campsites, climbers' camps, mountain passes and other viewpoints, and along trails, etc.). When wilderness Rangers must spend a large portion of their time ranging over broad geographic areas to pick up litter, they have less time to spend on other important duties such as visitor contact and education, maintenance of trails and facilities, and enforcing rules and regulations.

Applying the Incentive System in Wilderness and Backcountry

1. *First Year--1972--The Material Incentive Experiment.*

The U.S. Forest Service Recreation Research Project in Seattle, in cooperation with the Pacific Northwest Region of the Forest Service, began investigating the applicability of the incentive approach to litter control in wilderness environments in the summer of 1972.

A modified incentive system was employed in the Glacier Peak Wilderness Area of the Mt. Baker National Forest. As originally conceived, the incentive system used in the wilderness was little different than the developed-campground phase of the system. Wilderness Rangers passed out coupons to selected recreationists which they could later redeem at local sporting goods stores for a variety of items including posters, strawflower seeds, safety whistles, permanent matches, and stuff sacks, as well as a chance to win a backpack. All of these incentives were provided by a local outdoor equipment manufacturing company. In return for a coupon, the recreationist agreed to pick up and/or pack out specified amounts of litter from the area.

Upon identifying a litter problem during this study, the wilderness Ranger would adopt one of two approaches.

a. If the litter was concentrated around popular, heavily used areas (often day-hike destination areas), the Ranger would contact nearby recreationists, explain the nature of the litter problem, and request their participation in picking up litter and packing it out of the area in exchange for the coupons. Participating recreationists could then take the coupon to one of the cooperating merchants and pick out the incentive of their choice. They were told that by turning in their coupons, they were automatically in the running for the backpack that would be given away in a drawing at the end of the summer. If the recreationist chose to participate, he was given a litterbag with a coupon stapled to it and verbal instructions concerning where and what to pick up. The Ranger would then move on to other duties, (enforcing fire restrictions, trail maintenance, backcountry use education, etc.), or other areas, leaving the recreationist to pick up the area and carry the litter out with him.

b. If, on the other hand, the litter was in a remote area, or dispersed around a little-used area, the wilderness Ranger picked the litter up himself and then asked recreationists to carry it out with them in exchange for a coupon. Participants were asked to deposit the litterbags in the garbage cans at the trailheads.

The data we collected indicate that forty seven 5-gallon bags (235 total gallons) were carried out of the wilderness by recreationists over distances ranging from 1/2 mile to 18 miles. We recorded only two instances where backpackers failed to carry out the bags of litter after they promised to do so. Before-and-after counts of specific areas to determine the effectiveness of the pick-up and pack-out phase of the program indicated that reduction of litter on the ground ranged from 4 to 89 percent. Litter was reduced by an average of 40 percent over the 15 situations that were monitored. In addition to the amount of litter which we know was removed from the wilderness in exchange for the coupons, we handed out coupons in many other situations where it was impossible to monitor the actual amount of litter reduction and removal. In all, a total of 524 coupons were given out during this study.

Evaluation of the results indicated that further modification of the incentive procedure was necessary. Although recreationists were extremely cooperative, many reacted negatively to the nature of the incentives. Although the research staff has yet to hear a complaint from recreationists concerning Smokey Bear or Woodsy Owl items as incentives with children, many adult recreationists dislike the commercial aspects of the coupons provided by the outdoor recreation equipment company, which ostensibly "gave away" posters, safety whistles, and a "free" chance on a backpack in return for litter pick up. Some recreationists felt that the coupons were merely a public relations ploy, with the underlying motive of luring customers into stores where the company's equipment was for sale. In addition, a small percentage of backpackers objected to the use of *any* incentive to achieve anti-litter behavior. They felt that people should not be given rewards for behavior in which they should engage anyway.

As indicated above, backpackers' objections to redeemable coupons from a private company did not seem to stop them from participating in the program by picking up and packing out litter. However, only 55 of the coupons were redeemed. The low coupon redemption rate--10.5 percent--coupled with the high number of recreationists who participated in the program, indicated that perhaps tangible incentives were not needed in a wilderness litter program involving adults. It appeared that a request for aid from the Ranger combined with the common desire of recreationists to keep the wilderness clean, sufficiently motivated involvement in the program for most users who were contacted.

2. *Second Year--1973--Verbal Appeals as an Incentive*

As a result of the 1st year's study the approach used the following year was modified to exclude tangible incentives for adults. Since rewards such as Smokey Bear shoulder patches have proven extremely effective in motivating children to participate in anti-litter activities, whether in developed areas or wilderness, their use with children was continued. To involve adults, Forest Service wilderness Rangers relied on their altruistic motivation which was so evident during the previous year. Litterbags were again provided by wilderness Rangers who contacted recreationists. Data were collected in a variety of popular areas frequented by day hikers and backpackers by two wilderness Rangers each on the Darrington and Monte Cristo Ranger Districts of the Mt. Baker National Forest, and two research assistants from the Recreation Research Project.

During this year, fifty one 5-gallon bags (255 total gallons) were packed out of the wilderness. The actual amount may have been double that since the wilderness Ranger who contacted the most people (45 parties) did not keep a record of the amount of litter that was carried out. Verbal appeals and instructions from wilderness Rangers were used exclusively when soliciting assistance from recreationists in packing out litter, except that Smokey patches were used with five parties which included children.

This study demonstrated that verbal appeals, litterbags, and accompanying

instructions by wilderness Rangers serve as sufficient motivation to elicit anti-litter behavior, and that tangible incentives continued to be highly effective in developing anti-litter behavior in children.

3. *Third Year--1974--Testing Guidelines for Verbal Appeals*

Wilderness Rangers and members of the research staff tested different approaches under a variety of conditions during 1972 and 1973 in order to determine the best circumstances and procedures for involving the public in litter control. Based on this experience, guidelines were developed for litter control in wilderness environments using verbal appeals as the incentive. The objective of the 1974 study was to test the effectiveness of these guidelines as a tool for managing the wilderness litter problem.

The overriding lesson learned from the previous studies is that the effectiveness of a wilderness litter control program is highly dependent on a variety of situational variables. These variables can be constraining factors in terms of where and how a litter control program will be successfully implemented. Factors which significantly affect the successful implementation of the program include: (a) characteristic use of the area (e.g., day use, weekend use, of a more extended duration), (b) the nature of the job to be accomplished (e.g., picking litter up and packing it out, packing it out only, etc.). (c) characteristics of the recreationists or the recreation experience (e.g., age, available time, activities they are engaged in, etc.), (d) the nature of the incentive (e.g., an altruistic appeal vs. a tangible incentive, the type of tangible incentive, etc.).

The effects and influences of these and other variables must be incorporated into any litter program intended for use in a wilderness environment. In designing the following guidelines, we have attempted to consider the variables which we have identified as important.

For wilderness Rangers to successfully utilize the guidelines explained below, it is necessary for them to carry a sufficient quantity of litterbags and Smokey Bear and Woodsy Owl incentives to undertake a treatment when the situation warrants it. This requires planning to identify litter problems and user densities. With a little forethought, it should be fairly simple to schedule these activities into the Ranger's normal routine. The guidelines tested during this study involve the same concepts as those developed for use in roaded recreation areas, but they have been modified to account for problems which are specific to roadless areas.

4. *Guidelines.* The guidelines developed and tested during this summer consisted of four distinct steps.

Step 1. *Identify the Litter Problem.* The wilderness Ranger must first size up the nature of the problem: is the litter dispersed or concentrated, does it consist mostly of smaller items that can easily be picked up and packed out, is the area dirty enough to warrant treatment? The nature of the litter problem determines the next step in the procedure.

Step 2. *Contact users in the area, choose which collection method is appropriate to the situation, and explain the program.*

(a) *Pick up and pack out*--this approach is best utilized at a day-use area or a very popular backcountry destination. If the litter is fairly concentrated and can be easily picked up, the Ranger should contact parties in the area that have children or young adults with them (we have found that children in the 7-12 age group respond most enthusiastically). The Ranger should then approach the recreationists; and after a few pleasantries (e.g., are you enjoying your trip?), he should explain that the Forest Service, as part of its Pack-Out-Program, would like their help picking up and packing litter out of the area. The Ranger should show the incentives (Smokey Bear

or Woodsy Owl shoulder patches, etc.) to the children and tell them they can choose one if they help. Usually they will respond positively, and the parents will generally give permission for their children's participation.

(b) *Pack out only*--If the Ranger determines that the situation is inappropriate for involving recreationists in litter *pick up* (because of a lack of people, the dispersed nature of the litter, type of litter, or because backpackers are passing through the area carrying heavy packs, etc.), he should pick up the area himself. This usually occurs at remote backcountry sites, along trails, and near little-used lakeshores or hunter's camps. After the litter is bagged up and transported to a location where backpackers or day hikers are likely to visit or pass by, the users are contacted and their help in packing out litter is solicited.

Often it is awkward to stop people carrying heavy packs or who have their hiking momentum going, so the ranger must be sensitive when approaching backpackers who are traveling. After the contact is made and it becomes apparent they don't mind stopping, the Ranger should explain the program (as in the pick-up and pack-out phase) and ask if they would mind packing a bag or two of litter out of the area to dispose of it at home or in a convenient litter barrel along the way. It is extremely important at this point to determine whether the party is near the end of its trip. It is unreasonable to request people just beginning an extended hiking trip to carry bags of litter with them. It is appropriate to use tangible incentives for soliciting the help of any children with the groups.

Step 3. *Organize the Pick Up/ Pack Out Effort.*

(a) *Pick up and pack out*--After recreationists have indicated a willingness to help, the Ranger must explain to the parents and children specifically what needs to be done. He should request *specific tasks* rather than general help in litter control. He must explain to the children what areas need picking up, perhaps emphasizing that a special effort is needed with cigarette filters or other persistent litter. The Ranger can give the incentives either to the children in return for their assurances that they will clean the area, or he can give the incentives to the parents for distribution when the jo is completed. At this point, the Ranger should give each participant a litterbag and emphasize that the job is not complete until the litter has been picked up *and* packed out of the area.

(b) *Pack out only*--After contacting backpackers and hikers who have expressed interest in helping pack litter out of the wilderness, it is important to allow the recreationist to decide how much he wants to carry (which generally depends on his load and distance to travel). One backpacker packed out four full bags of litter during the 1972 study (on a level, 1-mile hike with light backpack); but a heavily loaded backpacker might indicate that one bag or less is enough. The Ranger should keep in mind that one objective of the program is to eliminate special trips by Forest Service personnel and pack stock. He should strive to meet his objective by encouraging hikers and backpackers to transport as much out of the wilderness as is comfortable. But the recreationist is the final decisionmaker.

Step 4. *Return to Other Duties.* After the participants are organized, the Ranger can then return to other duties such as public contact, trail maintenance, or site rehabilitation. An advantage of the system is that once the litter problem has been alleviated with the help of cooperating users, the Ranger is free to return to or take up other pressing management duties that require special skill or knowledge.

To ensure variablity during the test of these guidelines (i.e., variability of geographic area, user groups and wilderness Rangers), five wildernes

Rangers from several National Forests were involved during the 1974 field test. They were all instructed in the use of the system by Recreation Research Project personnel. The Ranger utilized a different approach depending on the specific situation encountered, i.e., (1) short trips involving day hikers, (2) extended trips involving backpackers, and (3) extended trips involving horse users. Table 1 summarizes the results of the data collected by the five Rangers during the 1974 field season.

and pack it out with them. They were also asked to pick up along trails. The participation of children, in exchange for shoulder patches, was used most often in a day-hike environment. Rangers made contacts with hikers during routing patrol trips to these areas.

Litter Control by Backpackers

Previous experience in 1972-73 indicated that the emphasis in wilderness litter control involving

Table 1--User contact and participation by user type--summer 1974

Contacts	Back-packers	Day hikers	Horse users	Total
Number of parties contacted	9	22	6	37
Number of people in the parties contacted	33	125	21	179
Amount of litter packed out (by 5-gallon bags)	13	52	18	1/ 83
Number of people who refused to participate 2/	3/ 2	4/ 13	4/ 3	18
Number of times Smokey Bear patch was employed	8	5	--	13
Number of times that verbal appeal and instructions were employed	8	17	5	27

1/ Total of 415 gallons of litter packed out.

2/ *Day hikers*--Two people in the party "didn't want anything to spoil their day." Other two members of the party packed out one bag each.

Backpackers--At the time of contact, the party had 8 miles to go in 2 days. They felt that they could not sustain the extra weight and bulk for that length of time.

Horse users--The party expressed the feeling that saddle stock cannot be used for both riding and pack work. Since they only had saddle horses, they felt it would be inappropriate to pack litter out on them.

3/ One party--two people in the party refused to participate but the other two people in the party agreed to carry out one bag of litter each.

4/ One party.

Litter Control

Involving Day Hikers

Day-hike areas often have litter concentrated in intensive-use areas such as lake shores, trails, and around popular fishing, sight-seeing, and camping spots. Hikers were contacted and asked to pick up litter in these areas of high concentration

backpackers should be on packing out litter that had already been collected and bagged up by the rangers, although users may be involved in picking up litter in certain locations. A major problem in wilderness is the way litter is dispersed--it often occurs in widely scattered, lightly used campsites (such as infrequently used hunter or fishermen's camps). This litter usually is most easily collected by the Forest

Service Ranger in routine visits to these areas. This "bagged" litter was then assembled at a central location on a main trail, at a shelter, or in a wilderness campground. At that point, the Ranger contacted backpackers to request their participation in carrying the litterbags out of the wilderness.

Litter Control by Wilderness Horse Users

A major problem in roadless recreation areas is that large items brought in by pack horse are often too heavy or bulky for Rangers or backpackers to carry out. These include items such as refrigerator racks, large cans, big plastic jugs, and abandoned cast-iron stoves. Horse users were utilized to help transport these items and large caches of litter out of the wilderness.

Involving wilderness horse users in a litter control program may present special problems. One unforeseen benefit of the Incentive System, however, which was discovered during its application in developed campgrounds and dispersed car camping areas is that the program provides the opportunity for positive public contact with members of specific user groups (Clark, Burgess, and Hendee 1972).

For example, in 1970 in the Taneum Creek area in the Wenatchee National Forest, Recreation Research personnel initially encountered indifferent or antagonistic receptions as they contacted users (who happened to be motorcyclists) at their campsite. This user group was used to being contacted or reprimanded about their rule-violating behavior (lack of spark arresters, noise and dust-related problems, using ORV's in prohibited areas, etc.) and, as a consequence, many saw contact with Forest Service patrolmen (as well as personnel from other agencies) as a negative experience.

The unfriendly, cold attitudes of ORV users in the Taneum area changed, however, when they perceived that Forest Service patrolmen were approaching them for another purpose. After the researchers explained the program, they resumed their usual duties, promising to return later to hand out incentives and collect full litterbags. On their return trips, they were given friendly receptions. Recreationists who had witnessed the enthusiastic participation of their children in a meaningful program were pleased with their new role of "cooperators."

There may be similarities between motorcycle users in dispersed camping areas and some horse users in wilderness environments, including the feeling that Forest Service regulatory enforcement is restricting their freedom. It is necessary that the Ranger who contacts the horse user with the intention of involving him in the litter control program do so sensitively. Forest Service personnel who have used the incentive system with off-road vehicle users have noted, however, that it can be the basis for a very positive public contact with this group, and if used correctly, the same result can be achieved with horse users.

To involve horsemen in the program, the Ranger should first collect the litter into manageable units. That is, he should carefully bag up the losse litter; using discarded plastic rain flys or canvas tarps to envelope cans, wire, broken glass, and other material which could gouge or poke a horse; bundle and tie old tin roofing material into compact sizes; squash 5-gallon cans; etc.; and do whatever else he feels is necessary to facilitate transportation of the litter by saddle or pack stock.

Once the litter has been "packaged" the Ranger should approach horse users in camp or on their way out of the wilderness, explaining that the Forest Serice has a major wilderness litter problem, and request the horse users' help in packing the litter out of the area. Many times the opportunity for more than a passing hello is nonexisten and the Ranger should not force the issue. Unless stopping the riders as part of checking for wilderness permits, it may be necessary to play a more passive role unless the packer

or rider indicates that he wants to stop and chat. Another opportune time to talk to horse users is when stopped to water their stock.

After the horse user indicates willingness to participate in the program, the wilderness Ranger should do all he can to assist the user in attaching the full litterbags to the packframe or saddlebags. Some users simply hold the litterbags by the drawstrings or loop them around the saddle horn and carry them out. Most horse users simply pack them right into the saddlebags or onto the packframe.

It is of the utmost importance, whether contacting the horse user or assisting him strap the litterbags to the packframe, to remember that many horses are skittish and do not respond favorably to strangers. Also, many horsemen are wary about strangers handling their stock. It is best, therefore, that the wilderness Ranger take his cues from the horseman regarding his behavior around the horses (in terms of stopping the group to chat, length of time spent talking to the riders, amount of help in strapping litterbags onto the saddlebags, etc.). If the litter to be packed out is noisy, sharp, heavy, etc., the user should be appraised of its condition and invited to inspect it or repack it any way he chooses.

Probably the most important aspect of the litter control program involving wilderness recreationists is that the Ranger should strongly emphasize that by picking up and/or packing litter out of the wilderness, the participants are providing much-needed assistance. He should, without exception, remember to thank them for cooperating in controlling this problem.

The data in table 1 and our observations suggest that wilderness and backcountry recreationists are a willing resource for controlling litter. The 415 gallons of litter and trash that were packed out by nearly 200 recreationists in 1974 would in previous years have been packed out by management personnel or it would not have been packed out at all. Litter packed out of the wilderness by Rangers and pack stock represents time and money that could be better spent on more important management activities.

The data further indicate the potential for involving different user groups to help control the litter problem. Horse users, backpackers, and day hikers all expressed a willingness to help. The data also confirm that the guidelines which we have developed can be flexibly employed as a supplement within the general "Pack-It-Out" framework by a perceptive and sensitive Ranger. But most importantly, the data indicate that adult wilderness recreationists respond very positively to verbal appeals for assistance and accompanying instructions from wilderness Rangers.

Conclusions and Additional Management Considerations

Recreation Research Project personnel have been involved in research, development, and application of the Incentive System for Litter Control since 1969. During this time, we have gained certain insights into different aspects of the litter control problem as a result of observations and contacts with many users and management personnel. We would like to take this opportunity to communicate some impressions to our forest manager colleagues.

These observations should be viewed as subjective impressions gained from an intensive involvement in this area of research rather than from empirically-derived data. Nevertheless, we offer these observations in the hopes that they may be helpful in understanding the full implications of the guidelines for litter control as they apply to roadless recreation environments.

1. *Contacting Special User Groups*

This report specifically addresses the problems and procedures of involving horse users, day hikers, and backpackers in a program to control wilderness litter. Thus far we have conducted no formal research geared to other roadless-area users, such as snowmobilers, motorcyclists, and cross-country skiers. We feel, however, that the logical extension of the Pack-It-Out Program to involve members of other recreation groups is not only feasible but desirable. One of the most important potential benefits of this system is that, by involving users, they may gain a sense of participation, pride, and responsibility regarding their public lands. This being so, it is important to involve a broad spectrum of recreationists so that the benefits derived by the various user groups, by the Forest Service, and by the general public will be increased. It should be relatively easy to adopt the system in such a way so as to extend coverage to these groups. There is no reason to think that members of these groups will not respond as positively to verbal appeals and Smokey Bear patches as do other recreation clientele groups.

Involving specific groups such as hunters and fishermen may, however, present special problems. The nearly unanimous consensus of the wilderness Rangers that we have worked with over the past 5 years is that hunters and, to a lesser extent, fishermen are responsible for a large proportion of the litter problem. This is not merely selective perception on the part of Rangers. A traditional attitude among some sportsmen, as exemplified by an article in *Sports Afield* (Jobson 1974), is that it is not always necessary or possible to pack out everything they pack in. Consequently, a challenge exists to develop incentives and implement guidelines for the successful involvement of hunters and fishermen in a wilderness litter control program.

2. *Contacting Backcountry Users, the Role of the Wilderness Ranger*

Throughout the research and implementation of the developed campground phase of the incentive system for litter control, members of the research staff were surprised at the reaction of many managers who expresse opposition to the incentive system. In other cases apprehension was expressed through the behavior of the Rangers or their supervisors who verbally approved of the system but refused to implement it.

We believe that much of the past resistance by Forest Service personnel to implement the system in unroaded areas is grounded in the same fears which initially created a reluctance in developed campground managers to apply the system there: namely, the unfounded perception that recreationists want a minimum of contact with Forest Service recreation managers, especially if it involves requesting assistance. The overwhelming positive public response to and acceptance of the procedures that have been developed demonstrates that these fears are seldom based on fact. Much of the day-to-day behavior of individual rangers may, however, be predicated on this particular perception.

The problem is accentuated by the fact that many of the people recruited for the wilderness Ranger position are wilderness recreationists themselves. They are aware, both through personal experience and exposure to environmental literature, that solitude is a prime value of wilderness and that there are strong social norms which minimize *interparty* contact in wilderness areas.

Our experience, however, suggests that although wilderness recreationists clearly seek to minimize contact with other parties, contact by a wilderness Ranger is not generally regarded as an intolerable social intrusion. Indeed, in many cases, recreationists actively seek out wilderness management personnel as a source of general information and expertise. Unfortunately, many wilderness Rangers have undoubtedly passed up opportunities for assistance in litter control as a result of this perception.

We do not intend to imply that there is no need for sensitivity to

the desire for solitude. Some people, especially wilderness purists, may consider such a contact as an intrusion. Contacts with anyone, including Rangers, may be undesirable in remote, off-trail zones; but there may be other areas (e.g., trunk trails, wilderness campgrounds, etc.) where the character of the users or the definition of the situation may be more amenable to contact and participation in the program without adversely impacting the wilderness experience.

Another consideration concerning the role of the wilderness Ranger is that they often perceive themselves as "garbage-collectors and fix-it persons." Wilderness management increasingly is being viewed as "people management". This is especially true of the wilderness Ranger's function. He often serves as the only link between the management agency and a special portion of its clientele. As such, it would seem desirable to spring him out of the "garbage-collecting" business and into a higher level of involvement where he is helping to manage behavior and, thus, the human impact on the wilderness resource. There are a wide range of important management activities (e.g., increased user contacts, site and resource inventories, gathering public input, disseminating management information, etc.) which a wilderness Ranger could become involved with if he were encouraged and reinforced to do so by institutional and supervisory mechanisms.

FLEXIBILITY IS THE KEY

One of the most important factors to be remembered in controlling wilderness litter is the need for flexibility. Forest Service personnel will probably always be involved somewhat with picking up and packing litter out of wilderness environments. Sometimes recreationists will not be available to participate in litter control activities. At other times people may be available but for one reason or another will choose not to be involved.

Primary objectives of litter control programs in wilderness environments, however, should be to eliminate "special effort" trips by Forest Service personnel and pack stock undertaken for the sole purpose of picking up and packing litter out of the wilderness, and to free wilderness Rangers for other important duties. An imaginative, perceptive wilderness Ranger might very well come up with modifications of these procedures which are better suited to local conditions.

For example, one wilderness Ranger involved the District trail crew in the pack-out phase of the program. Another wilderness Ranger built up rapport with one packer in her area to the extent that the packer regularly stops to ask if she has any bagged up litter to carry out to the trailhead. Another Ranger cached bagged-up litter near a popular shelter and in the course of his visitor contact duties, asked backpackers if they would mind carrying out a bag or two if they were passing that particular shelter on their way out. One District has had good results with caching bagged litter and supplying maps of these caches to a variety of organized user groups (Scouts, Outward Bound, etc.) who take some of this bagged-up litter out with them. One Ranger left bags of litter on the trail with a note attached which requested backpackers to carry it out with them. This same Ranger had successful results using lunch-sack-size cellophane bags instead of traditional 5 gallon litterbags. We are also aware of other innovative modifications. We feel that supervisors would be well-advised to encourage their personnel to experiment within the general guidelines described in this paper.

It is our belief that if the modified incentive system which we have described can be integrated into the Pack-It-Out Program, it will result in the increased effectiveness of litter control efforts in wilderness environments. In addition, by involving the public in the participatory control of the litter problem, sustained, long-term anti-litter attitudes may be fostered which will also contribute to the eventual elimination of the litter problem in unroaded recreation areas.

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